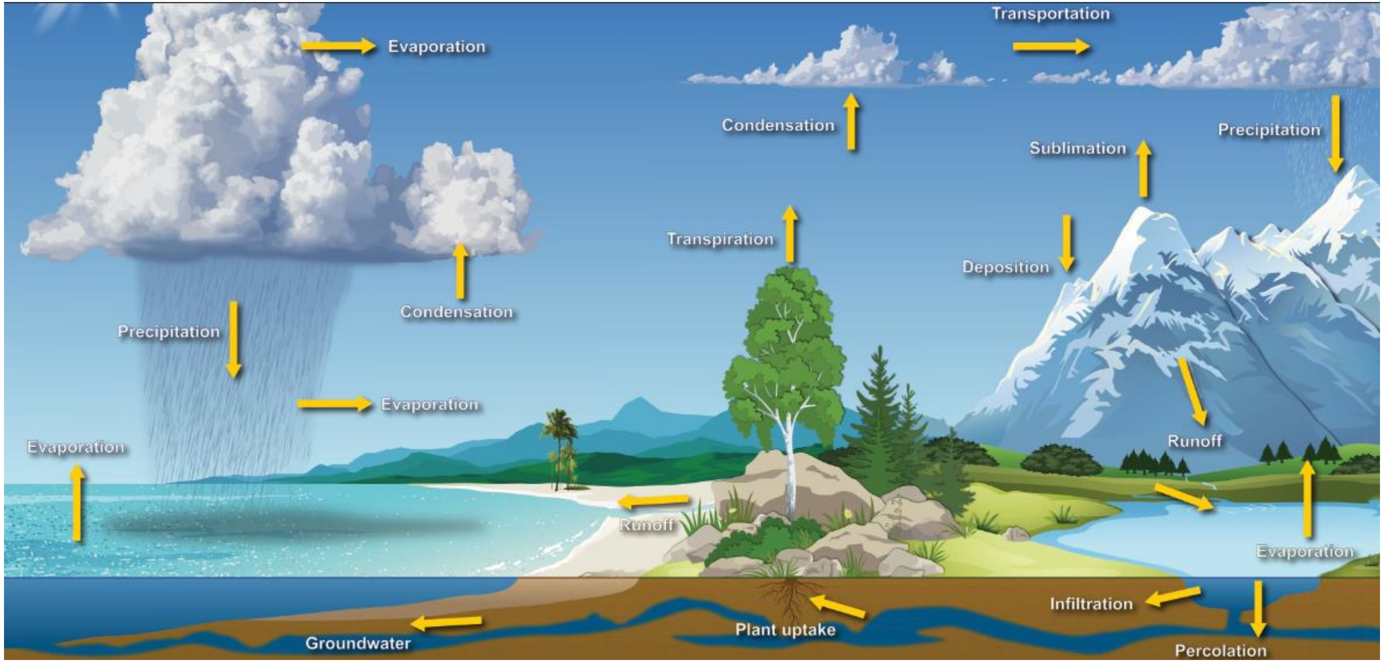
Effects of groundwater changes on coastal dune ecosystems

insights from mediterranean and tropical ecosystems

centre for ecology, evolution and environmental changes

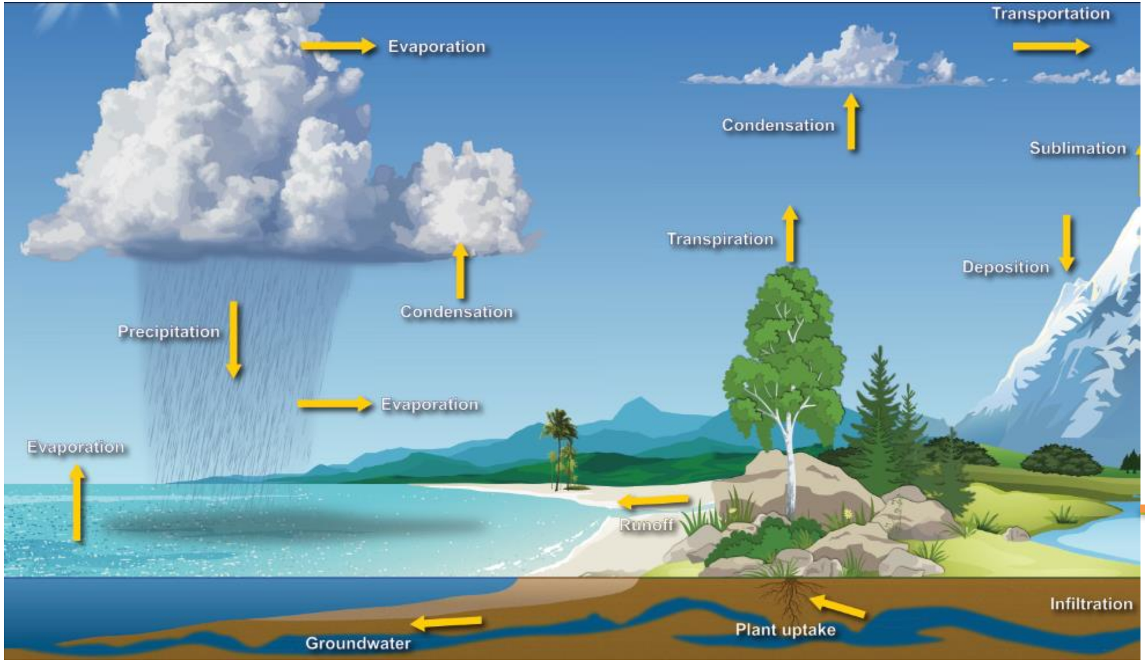
Cristina Antunes
cmaantunes@fc.ul.pt

Water cycle

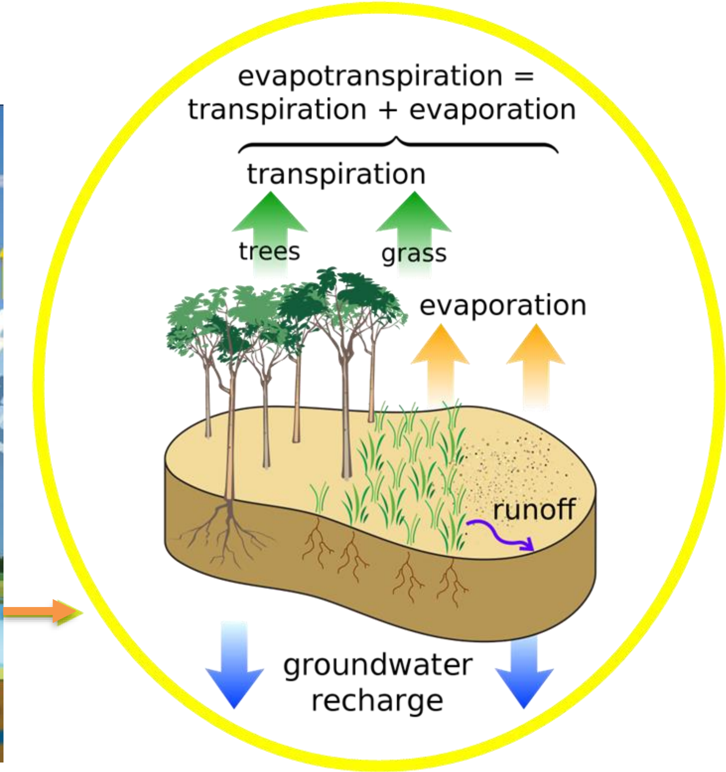


noaa.gov/education

Water cycle



noaa.gov/education



Water scarcity

United Nations | Climate Action

Water – at the center of the climate crisis

Climate change is exacerbating both water scarcity and water-related hazards (such as floods and droughts), as rising temperatures disrupt precipitation patterns and the entire water cycle.

water scarcity occurs when natural water resources are insufficient to meet all demands, including that needed for ecosystems to function effectively.

(long-term) imbalance between water demand and supply.

Water scarcity

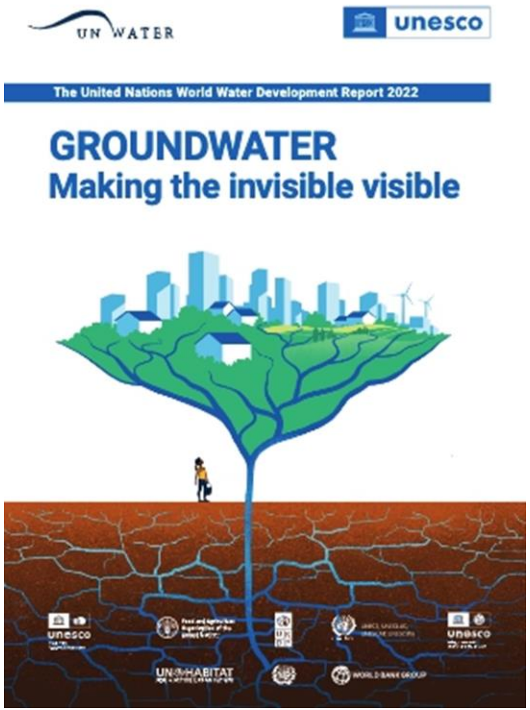
United Nations | Climate Action

Water – at the center of the climate crisis

Climate change is exacerbating both water scarcity and water-related hazards (such as floods and droughts), as rising temperatures disrupt precipitation patterns and the entire water cycle.

- half of the world's population is experiencing severe water scarcity for at least part of the year (IPCC).
- climate change, population growth and increasing water scarcity will put pressure on food supply (IPCC) - as most of the freshwater used, about 70 per cent on average, is used for agriculture (FAO).
- about two billion people worldwide don't have access to safe drinking water today (SDG Report 2022).
- water supplies stored in glaciers and snow cover are projected to further decline over the course of the century, thus reducing water availability during warm and dry periods in regions supplied by melt water from major mountain ranges (IPCC).
- sea-level rise and groundwater overexploitation are projected to extend salinization and decrease freshwater availability for humans and ecosystems in coastal areas (IPCC).

Groundwater



GROUNDWATER

Critical for Sustainable Development

Groundwater represents close to 99% of all unfrozen fresh water in the world. Groundwater makes up one third of all water being used, provides almost half of the world's population with domestic water[1], and is the source of almost half of the water used for irrigation worldwide.

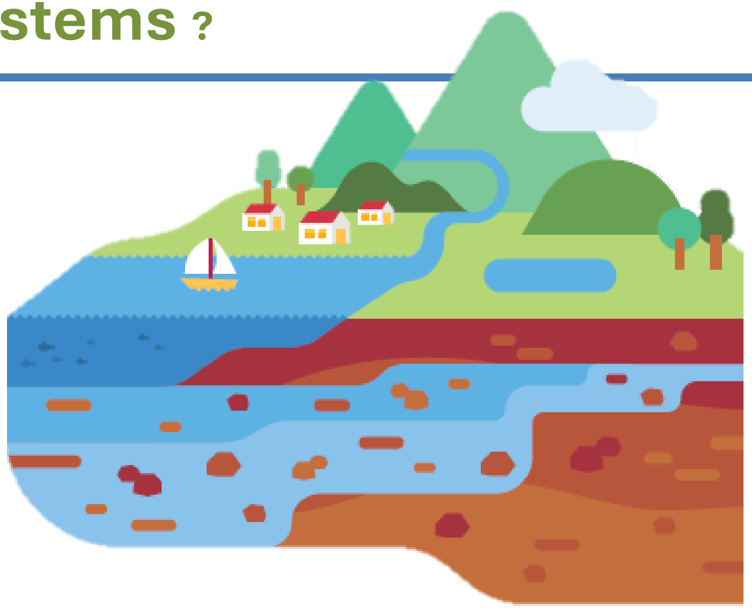
Groundwater underpins many terrestrial and aquatic ecosystems, and is critical for a host of the ecosystem services and natural habitats on which humans depend.

CGIAR Research Program on Water, Land and Ecosystems

IWMI

GRIPP Groundwater Solutions Initiative for Policy and Practice

What are **groundwater dependent ecosystems ?**



For most plants, rainfall infiltrated in soil is the dominant source of water available, but there is a class of vegetation that routinely uses **groundwater** to support growth and photosynthesis.
This vegetation is *groundwater dependent* because the absence of groundwater has a negative impact on the growth and health of the vegetation.

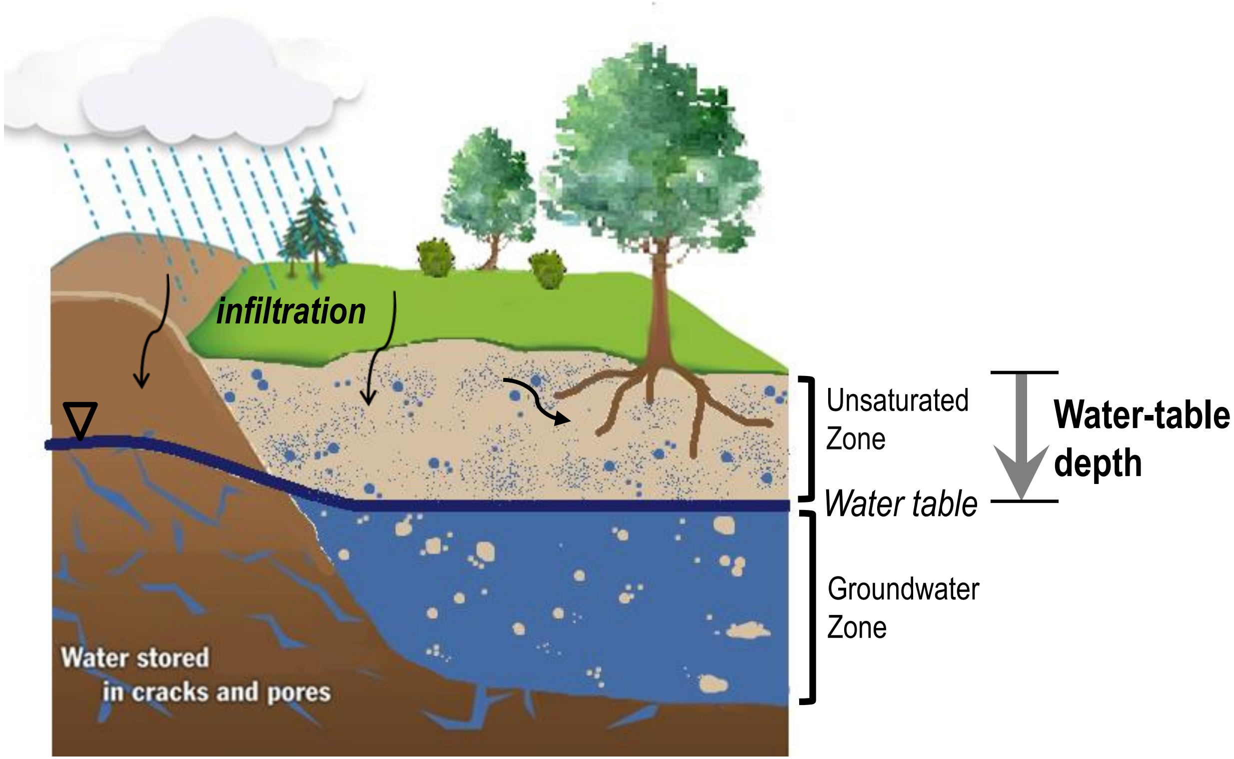
GW make up around **99%** of fresh water in liquid form – the remaining 1% corresponds to surface waters from lakes, rivers and other watercourses

Groundwater : water present beneath soil surface in soil pore spaces and in the fractures of rock formations. It is a water-saturated layer underground. GW also contributes to surface water as rivers, lagoons or temporary ponds

Water-table variations

Groundwater can serve as an important water resource for vegetation

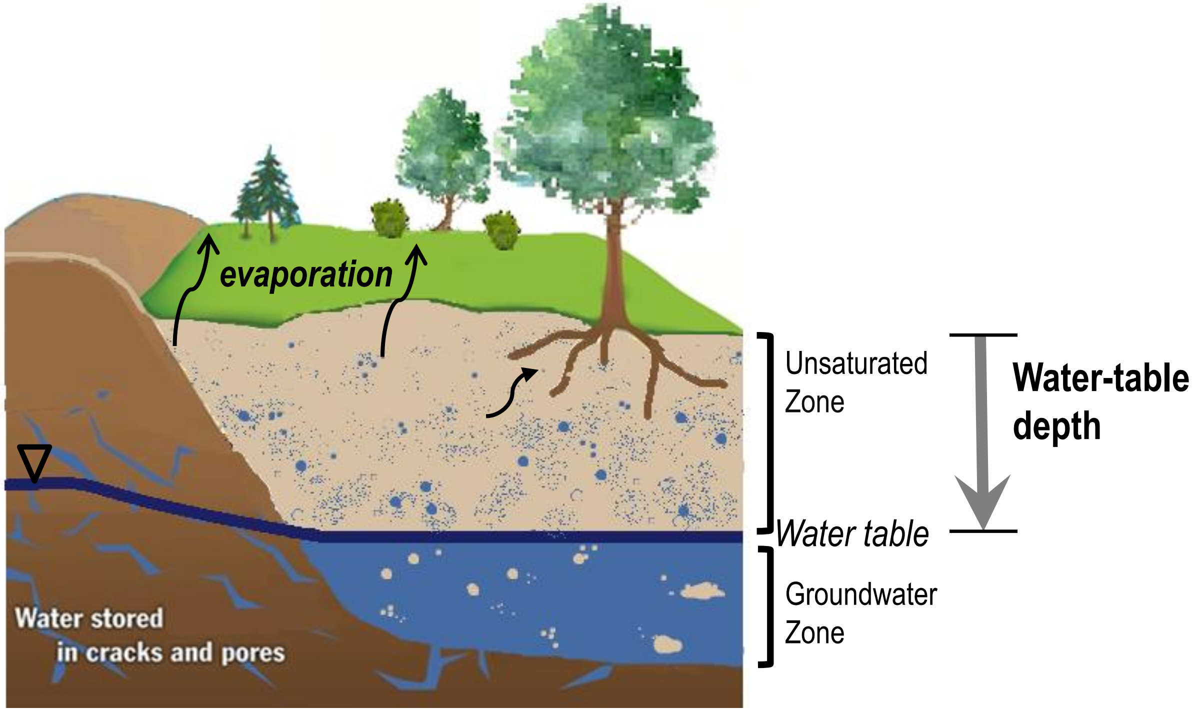
Fluctuations in water table level might affect plants



Water-table variations

Groundwater can serve as an important water resource for vegetation

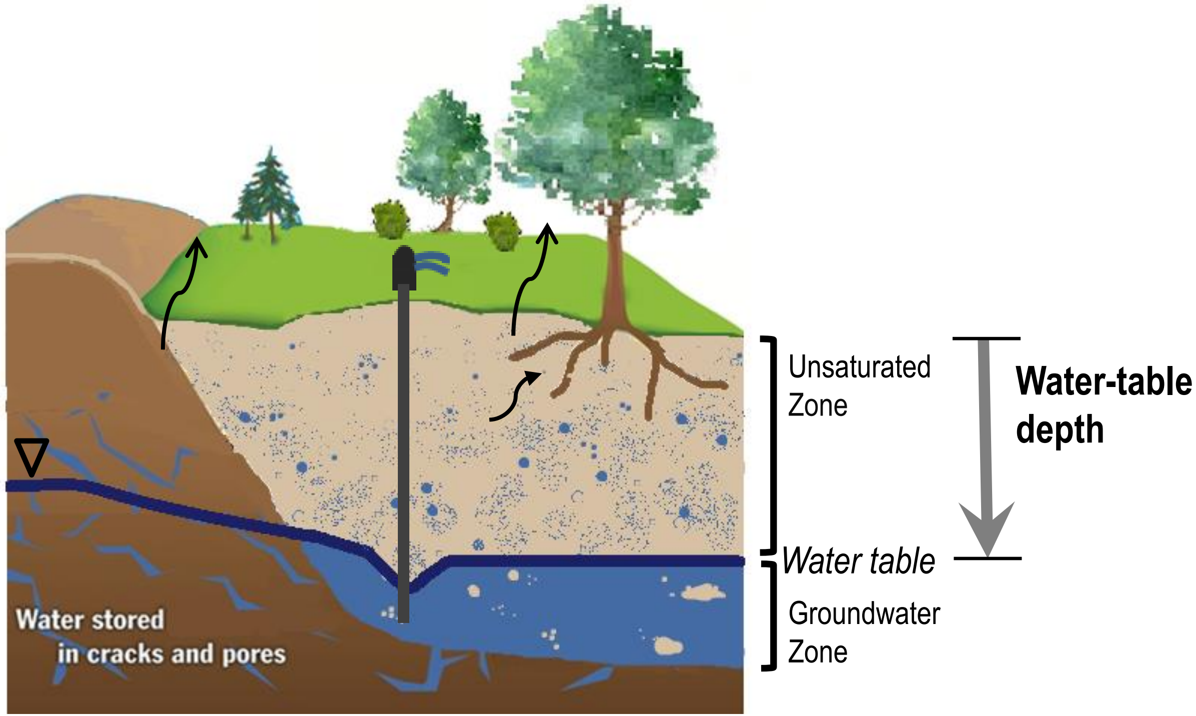
Fluctuations in water table level might affect plants



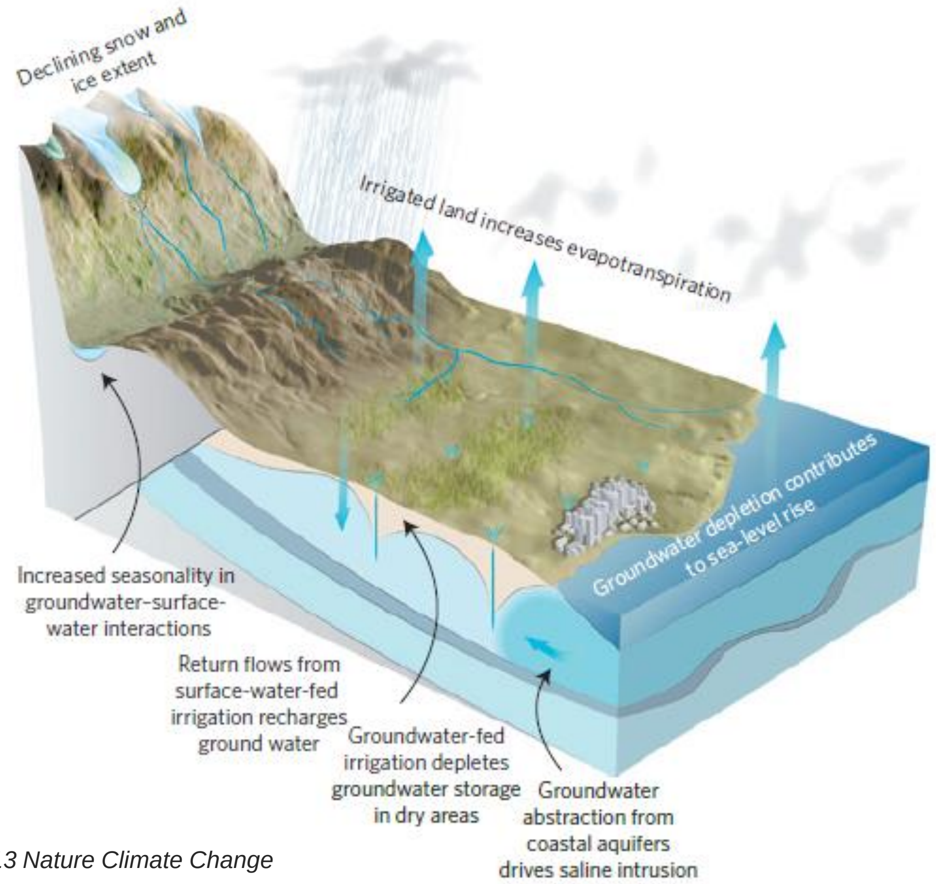
Water-table variations

Groundwater can serve as an important water resource for vegetation

Fluctuations in water table level might affect plants



Groundwater and **climate change**



Taylor et al 2013 Nature Climate Change

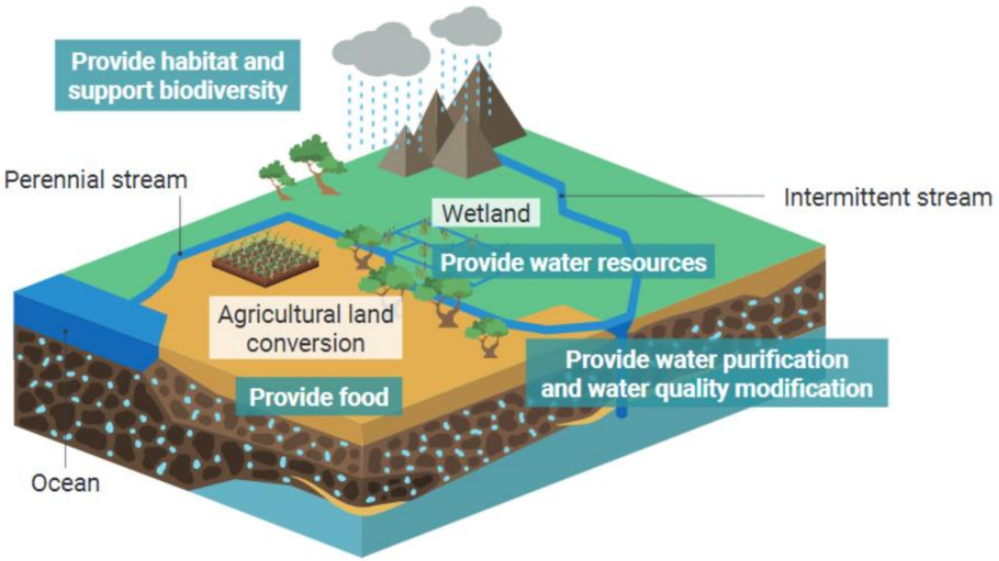
Groundwater plays a central part in sustaining ecosystems and enabling human adaptation to climate variability and change.

More frequent and intense climate extremes (droughts and floods) increase variability in precipitation, soil moisture and surface water, as well as anthropogenic water demand and groundwater-use.

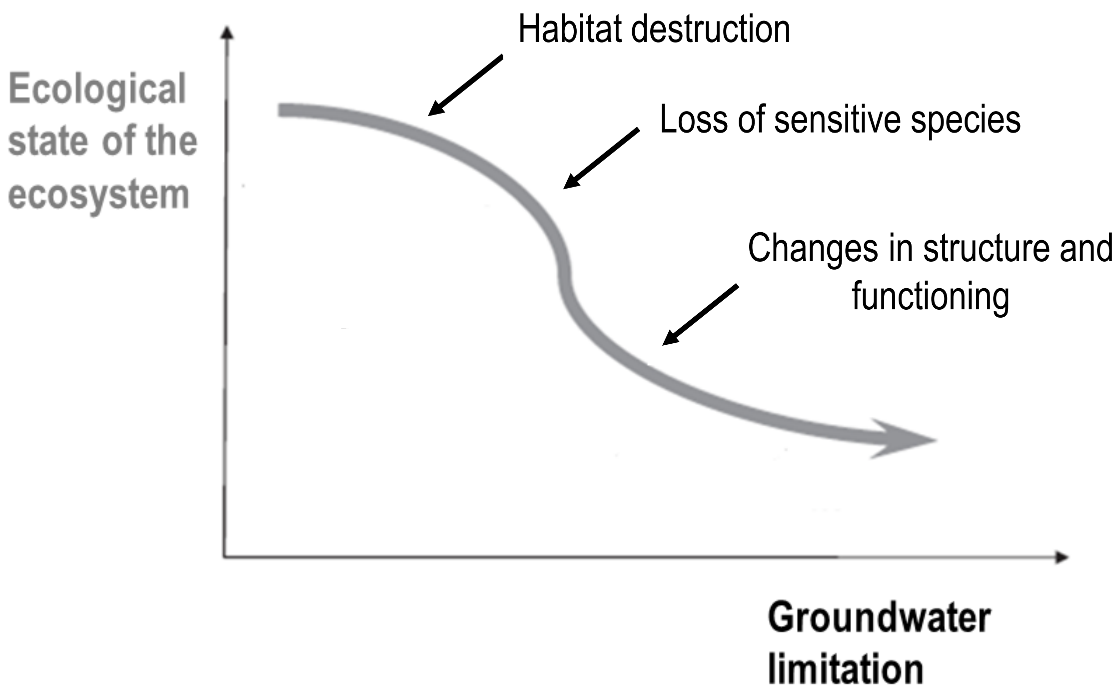
Why should we care about GDEs?

Besides the great ecological value of their biodiversity, these ecosystems are important for commercial value (for example plantations), for tourism value (as tourists like to see rivers flowing and healthy), for animals (for example temporary ponds sustain specific fauna, and riparian forests provide pathways for the movement of animals across fragmented landscapes), for stopping the development of dryland salinity, to hold onto soil and capture run-off maintaining land and water quality.

GDEs and groundwater support many ecosystem services



Why should we care about them?



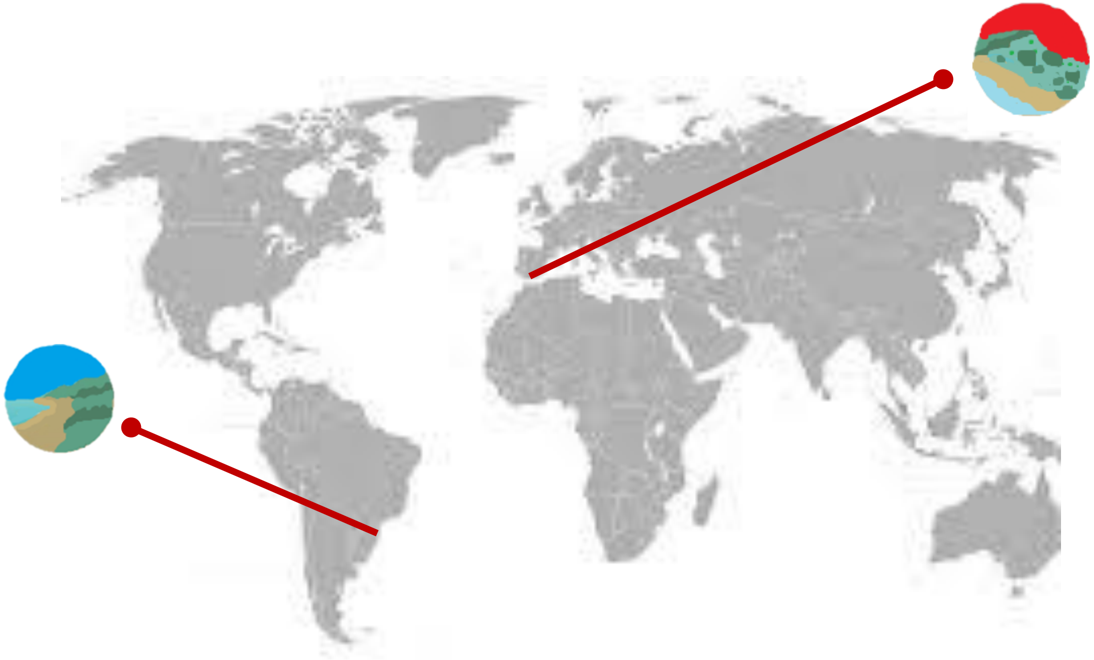
Adapted from: Kløve. 2013. *J.Hydrol*

Effects of GW changes in coastal dune ecosystems

- Groundwater is particularly important for ecosystem water balance
- Sandy poor soils with rapid water depletion and infiltration
- Shallow water-table (harboring temporarily flooded habitats)
- Dynamic water-table
- High anthropogenic pressure (e.g water demand)

Effects of GW changes in coastal dune ecosystems

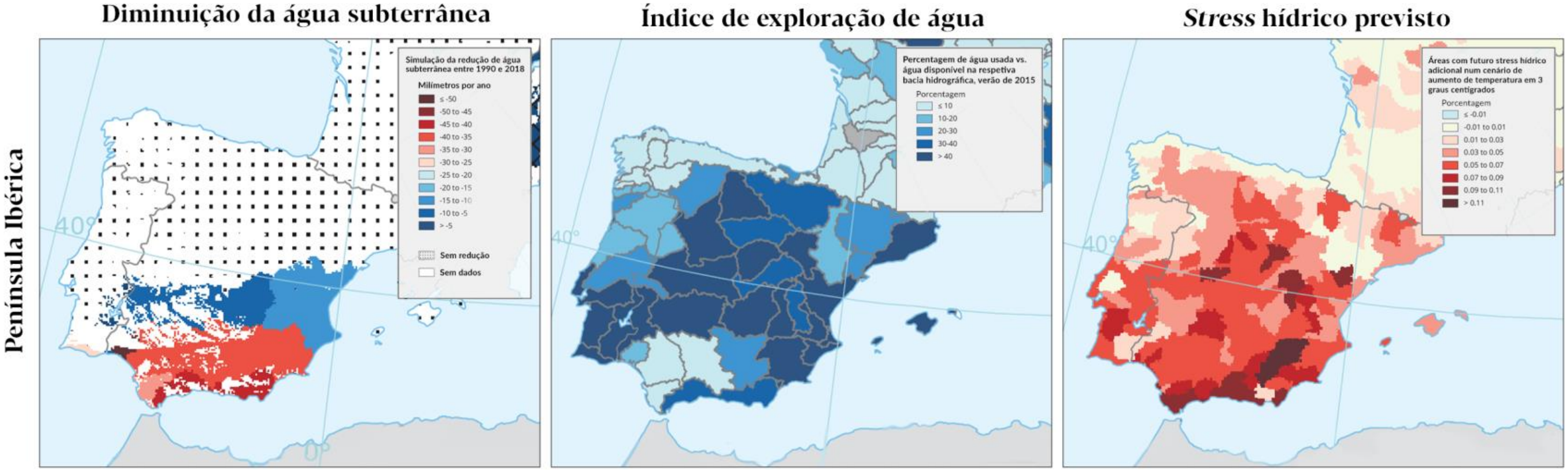
Insights from a **tropical** and a **mediterranean** ecosystem



Where?

In several areas of the globe, a reduction in the water table is expected. In areas with greater aridity, such as the south of the Iberian Peninsula, the pressure on groundwater resources and the predicted water scarcity is very high.

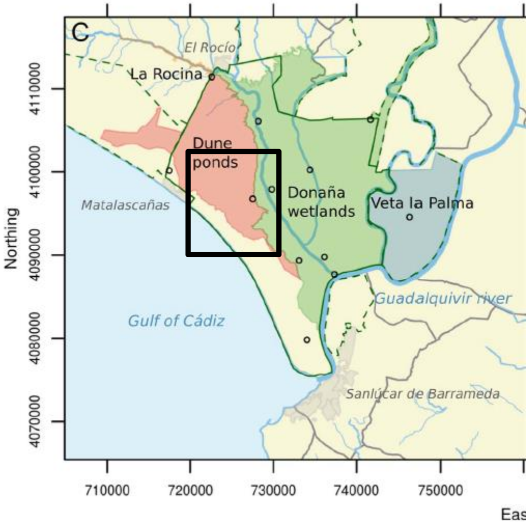
Vulnerable areas to (ground)water resources changes



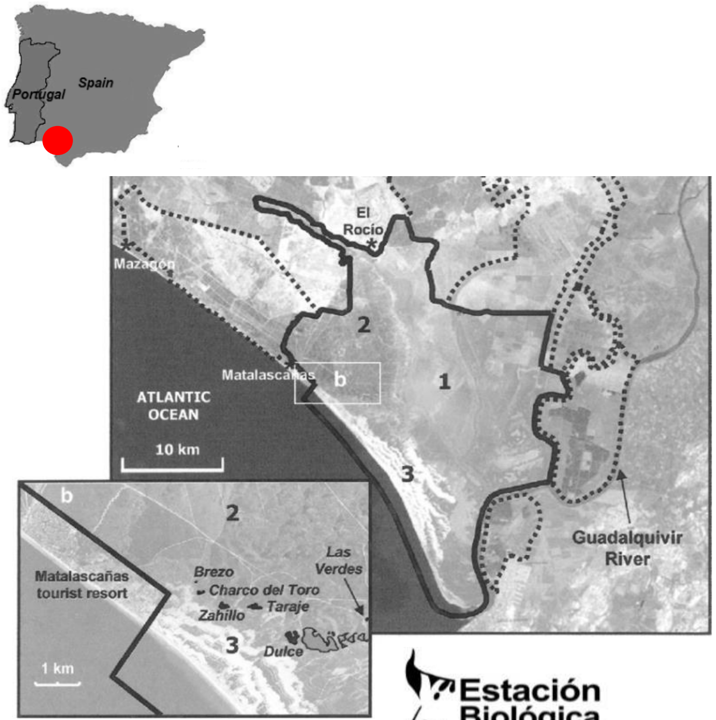
Fonte: Agência Europeia do Ambiente: Diminuição de água subterrânea, Índi+ce de exploração de água e *Stress* hídrico.

Where?

In coastal dune ecosystems, such as **Doñana** (SW Spain), groundwater is particularly important for ecosystem water balance.



Where?



Estación Biológica Doñana CSIC

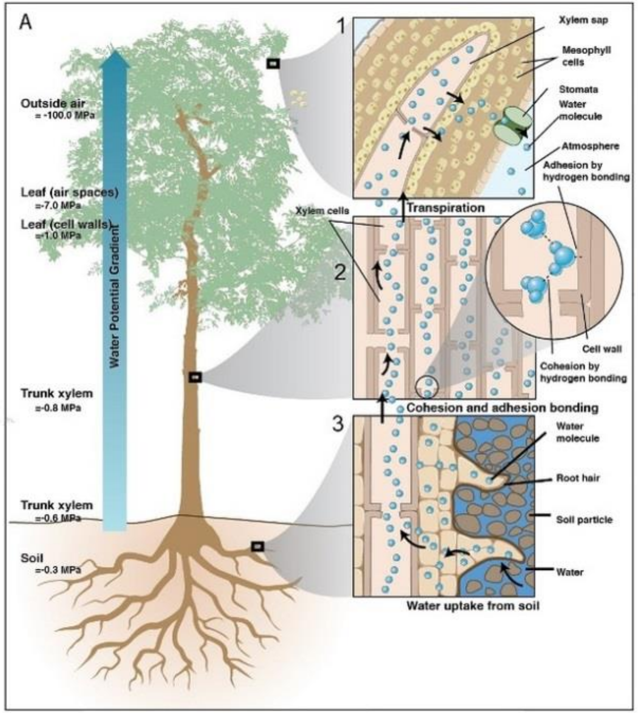
from [here]()

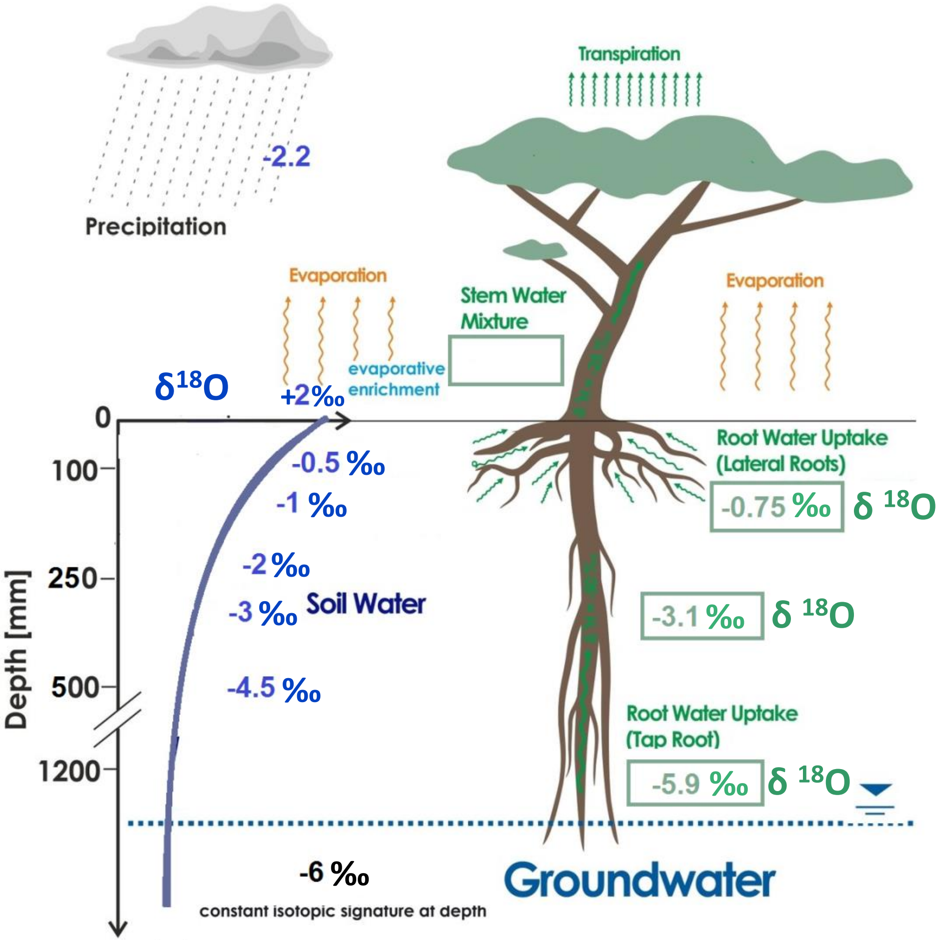
groundwater depletion, due to excessive human groundwater extraction for irrigation (e.g. extensive strawberry fields) and for touristic center water-supply. This, accompanied by low precipitation trends, has already led to the drying of temporary (and even permanent) ponds in the area.

1. Water-sources used by woody species

Isotopic approach

Continuum soil-plant-atmosphere





isotopic signatures

1. Water-sources used by woody species

Xylem water

✓ Dominant coexisting woody species

n= 18plots x 4sp x 3replicates = 216

Cistus libanotis
Cistus salviifolius
Corema album
Erica scoparia
Halimium calycinum
Halimium halimifolium
Helichrysum italicum
Juniperus phoenicea
Lavandula pedunculata
Phillyrea angustifolia
Pinus pinea
Quercus suber
Rosmarinus officinalis
Stauracanthus genistoides
Ulex australis

1. Water-sources used by woody species

Xylem water

- ✓ Dominant coexisting woody species

n= 18plots x 4sp x 3replicates = 216

Water sources

- ✓ Rainwater
- ✓ Groundwater
- ✓ Soil water

10 cm *n*= 18plots x 3 replicates = 54

30 cm *n*= 54

50 cm *n*= 54

N total = 162

1. Water-sources used by woody species

Xylem water

✓ Dominant coexisting woody species

n= 18plots x 4sp x 3replicates = 216

Water sources

✓ Rainwater

✓ Groundwater

✓ Soil water

10 cm *n*= 18plots x 3 replicates = 54

30 cm *n*= 54

50 cm *n*= 54

N total = 162

Quantification of water sources used by plants

Oxygen isotopic composition of water ($\delta^{18}O$)

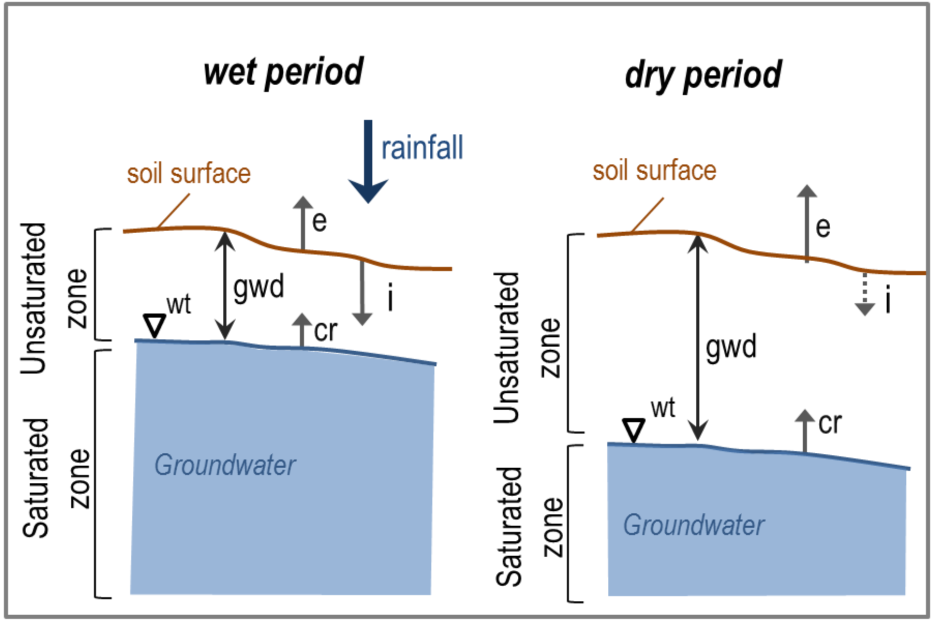
Bayesian isotope mixing models (MixSIAR)

→ **estimation of plant water uptake depth**

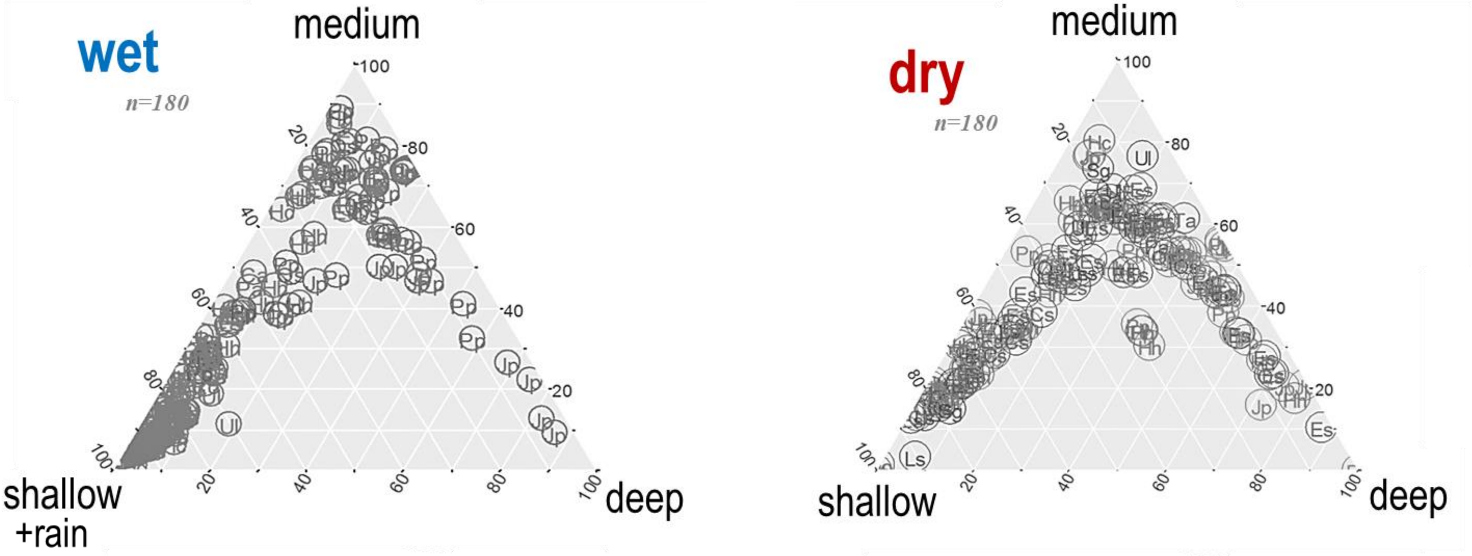
1. Water-sources used by woody species seasonally

Which are the strategies of water-sources-use under contrasting groundwater availability conditions?

GW temporal variations

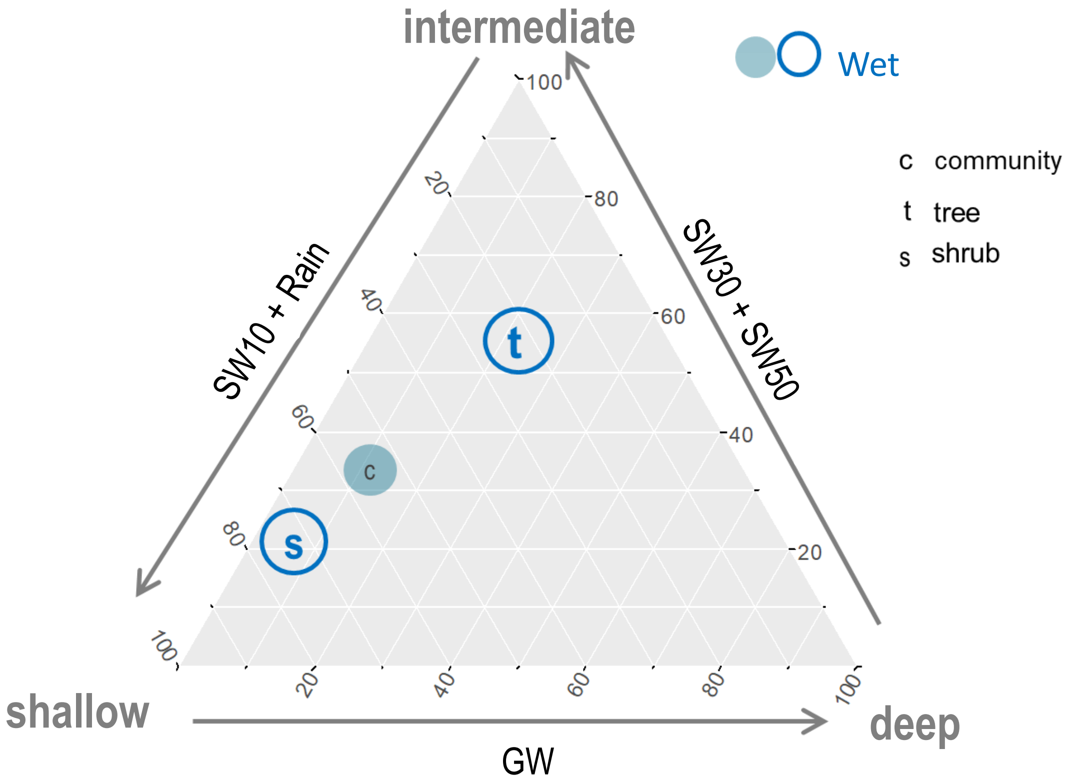


1. Water-sources used by woody species seasonally



Antunes, C et al (2018) *Journal of Vegetation Science* 29

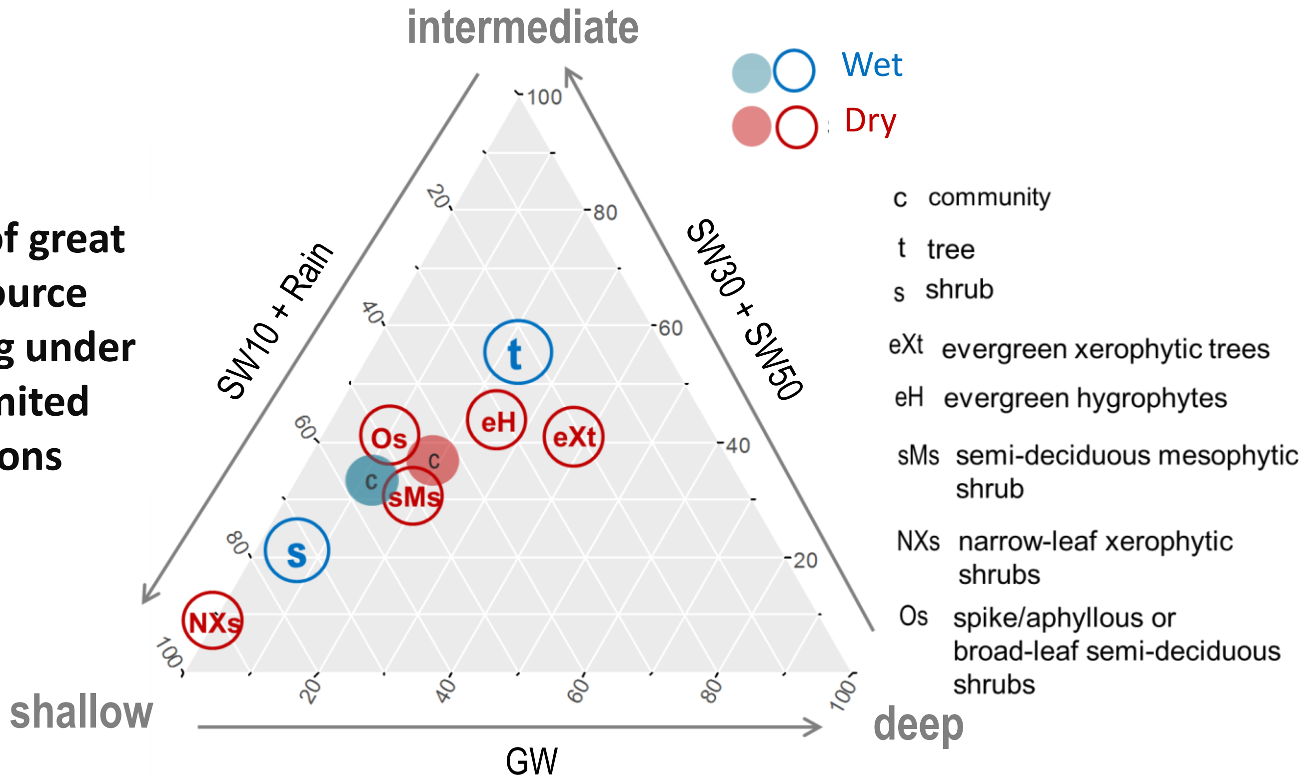
1. Water-sources used by woody species seasonally



Antunes, C et al (2018) *Journal of Vegetation Science* 29

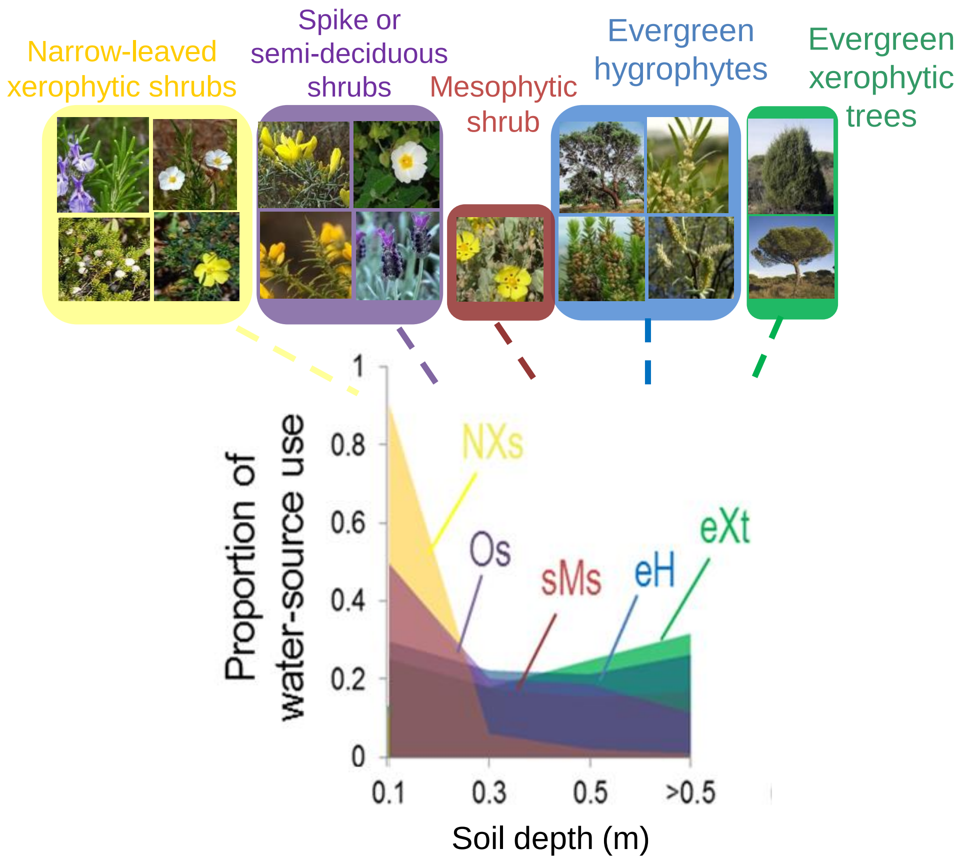
1. Water-sources used by woody species seasonally

Evidence of great water-source partitioning under water limited conditions



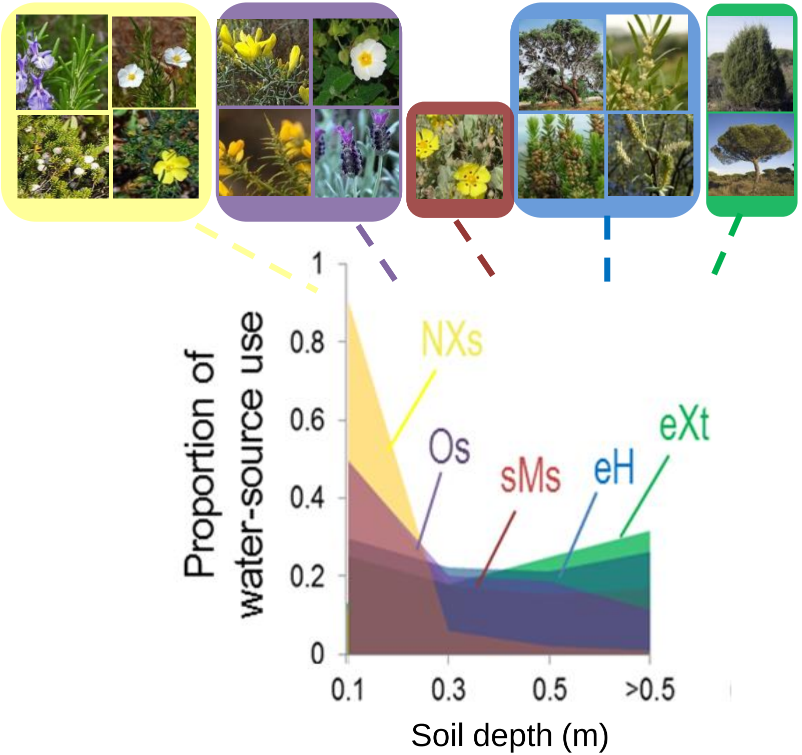
Antunes, C et al (2018) *Journal of Vegetation Science* 29

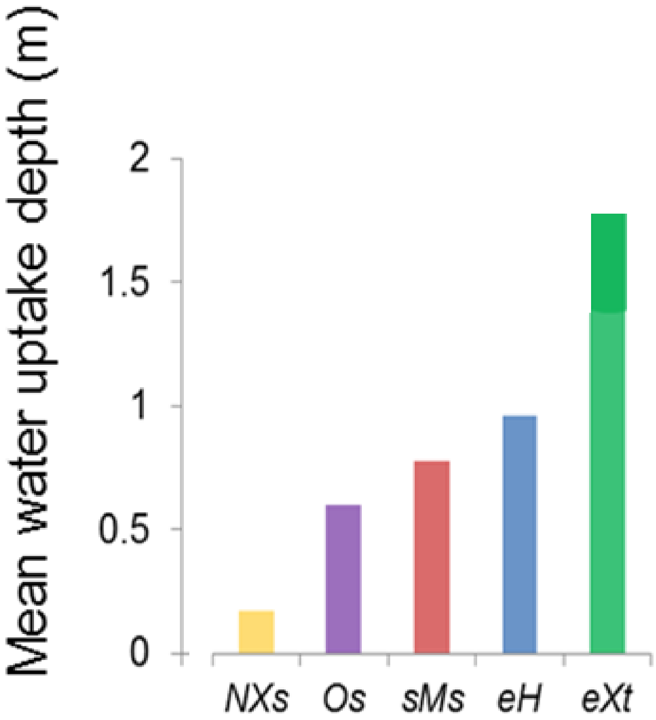
1. Water-sources used by woody species



Antunes et al (2018) *Journal of Vegetation Science* 29

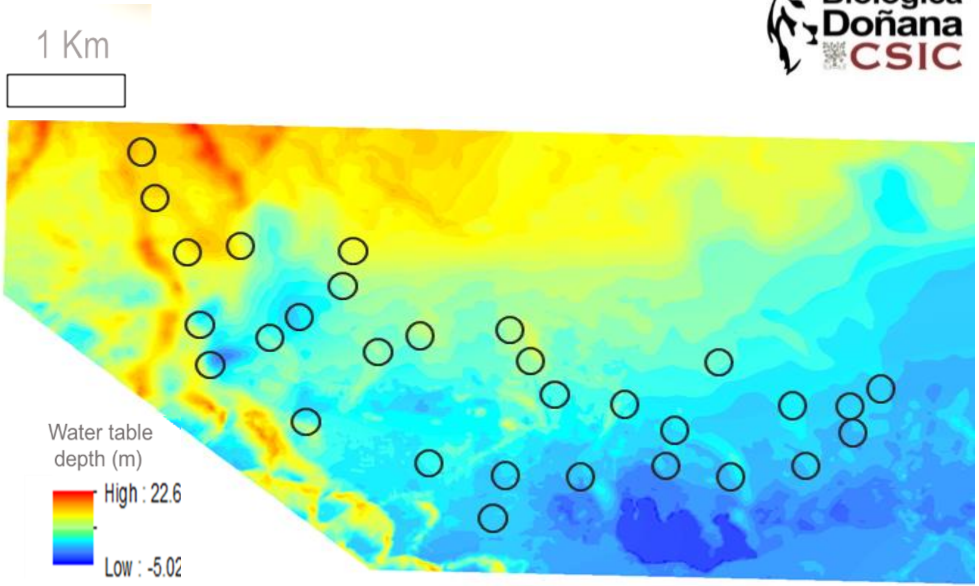
1. Water-sources used by woody species





Antunes et al (2018) *Journal of Vegetation Science* 29

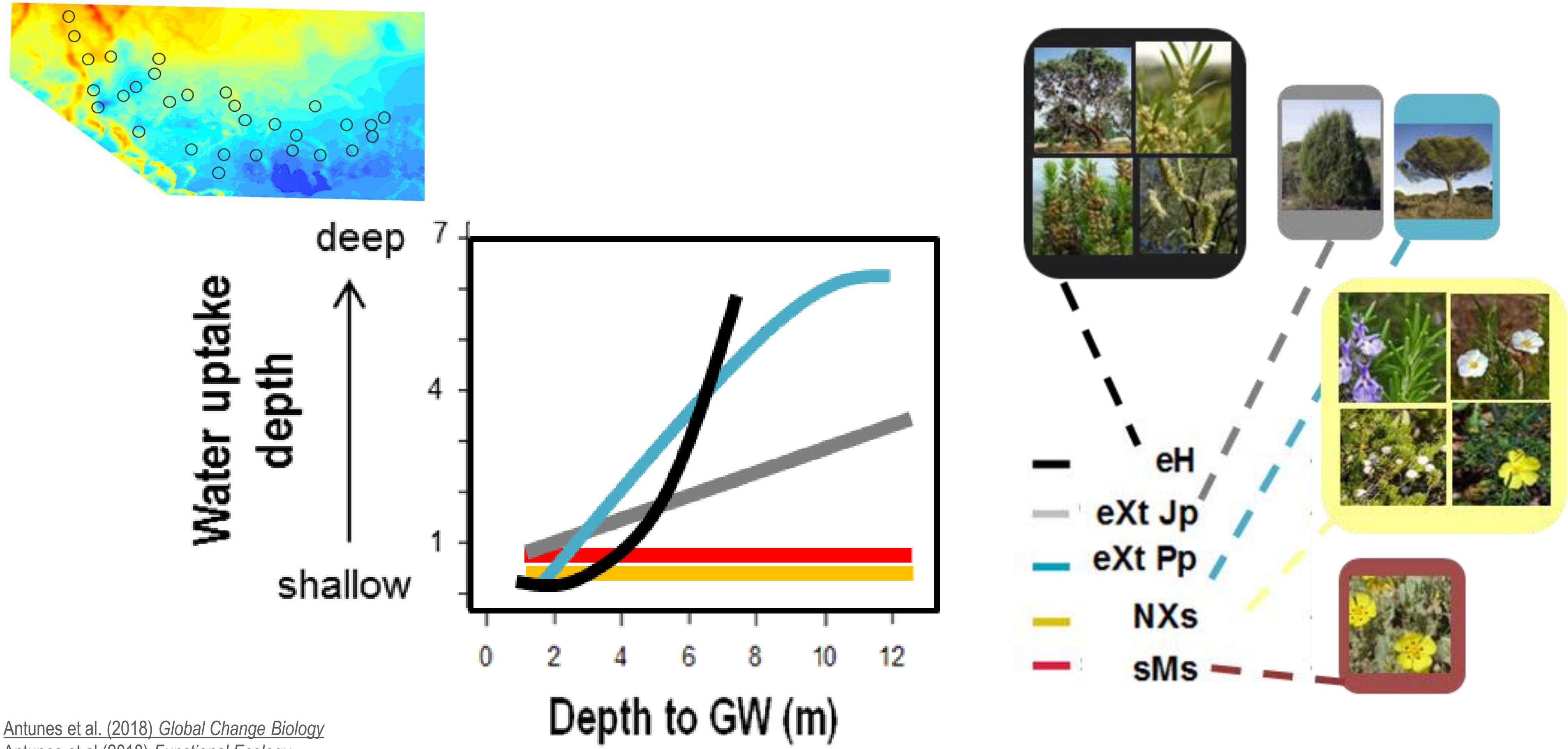
1. Water-sources used by woody species – GW gradient



Antunes et al. (2018) *Functional Ecology*

seasonally dry semi-arid coastal dune ecosystem, where human pressure is currently high, exacerbating climatic trends of groundwater scarcity

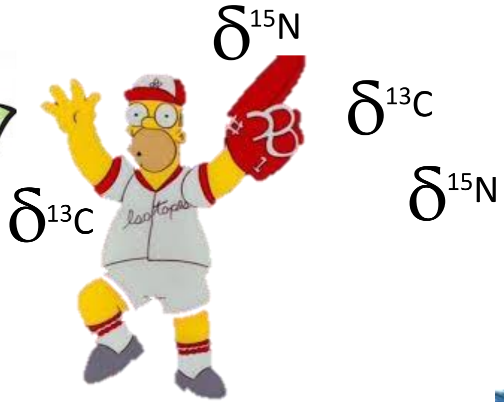
1. Water-sources used by woody species



Antunes et al. (2018) *Global Change Biology*
Antunes et al (2018) *Functional Ecology*

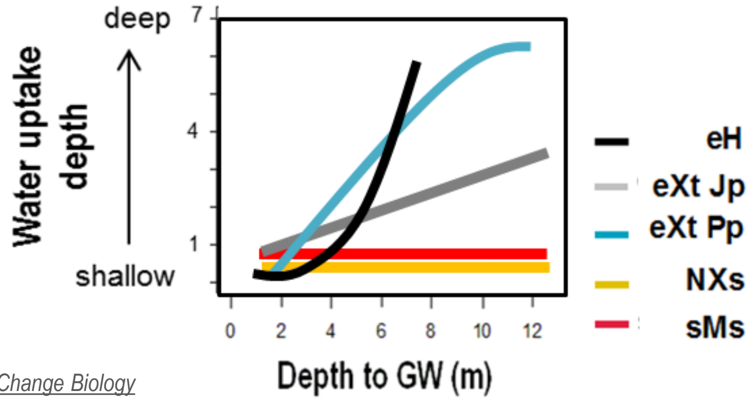
2. Ecophysiological responses to water-table depth

- Physiological parameters



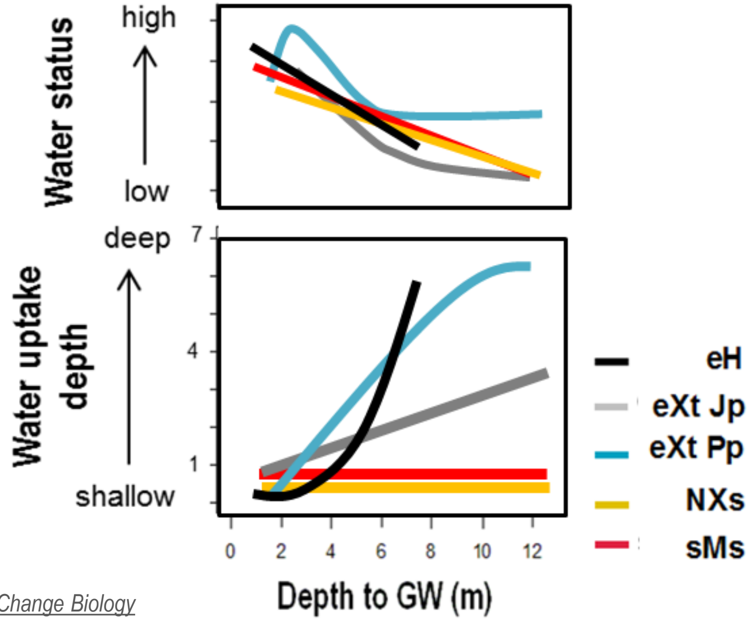
  - ✓ Leaf $\delta\ ^{13}C$
  - ✓ Leaf $\delta\ ^{15}N$
  - ✓ Leaf C
  - ✓ Leaf N
  - ✓ Reflectance Indices
    - Photochemical index (PRI)
    - Water index (WI)
    - Chlorophyll content index (CHL)
    - Normalized difference vegetation index (NDVI)

2. Ecophysiological responses to water-table depth



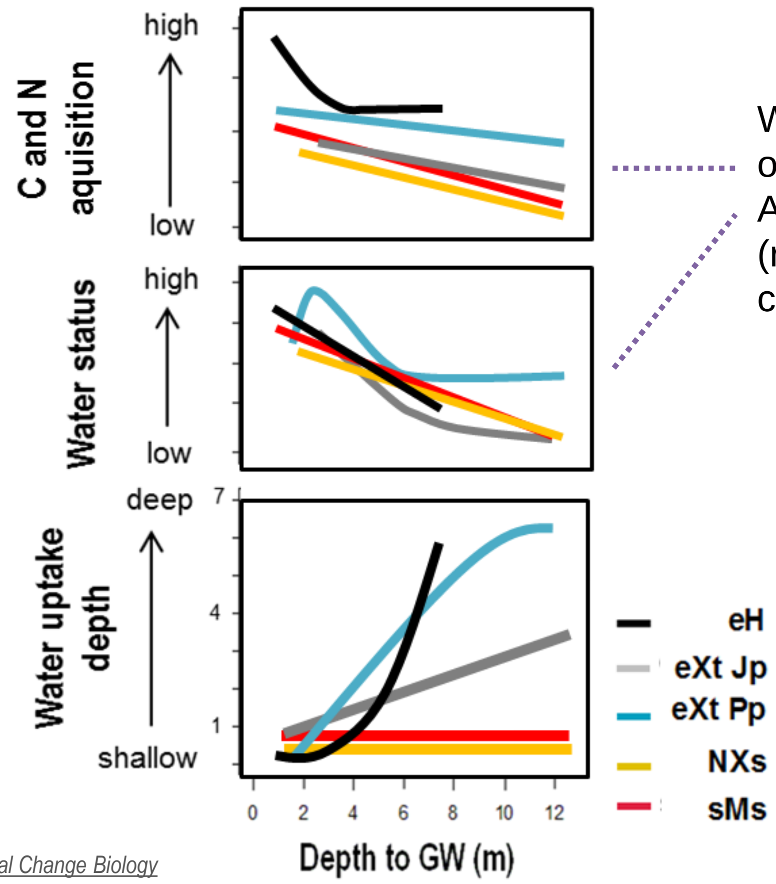
Antunes et al. (2018) *Global Change Biology*
Antunes et al (2018) *Functional Ecology*

2. Ecophysiological responses to water-table depth



Antunes et al. (2018) *Global Change Biology*
Antunes et al (2018) *Functional Ecology*

2. Ecophysiological responses to water-table depth

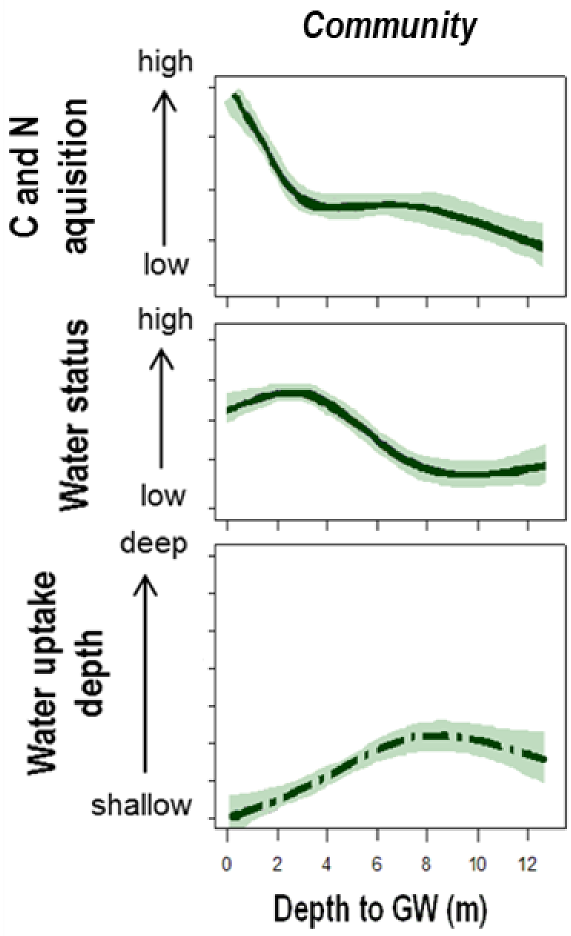


Water-table depth was a commom driver of declines of C and N aquisition and plant water status. Although varying in their water-sources-use strategy (root system), there is a systematic physiological constrain.

All plant functional types declined their vitality with GW lowering

Antunes et al. (2018) *Global Change Biology*
Antunes et al (2018) *Functional Ecology*

2. Ecophysiological responses to water-table depth



Woody species' community under this semi-arid hydrological context are highly susceptible to suffer from water-table depletion.

The **woody community of Doñana stabilized dunes is vulnerable to groundwater changes** and will be impacted by groundwater drawdown.

Implications for the conservation of plant communities that now face changing hydrological conditions caused by water extraction and climate change

3. Functional implications of water-table lowering

'Physiology'

- physiological parameters;
- seasonal water-sources-use;
- potential water-uptake depth

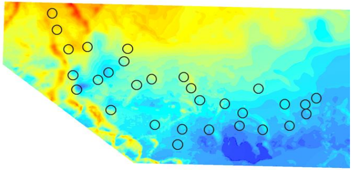
Antunes, C. et al. (2018) *Global Change Biology*
Antunes, C. et al (2018) *Journal of Vegetation Science*
Antunes, C. et al (2017) *Functional Ecology*

3. Functional implications of water-table lowering

'Structure'

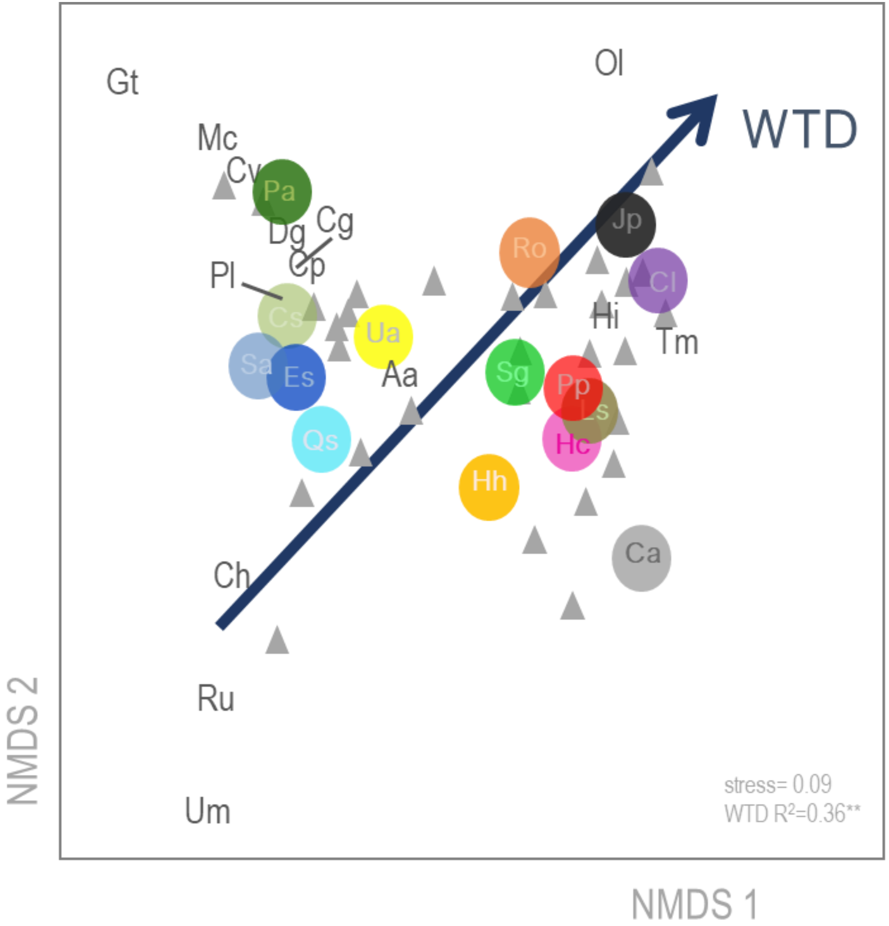
- Cover [transect-intercept method];
- Height;

woody species
at **29** sites distributed along the water-table gradient



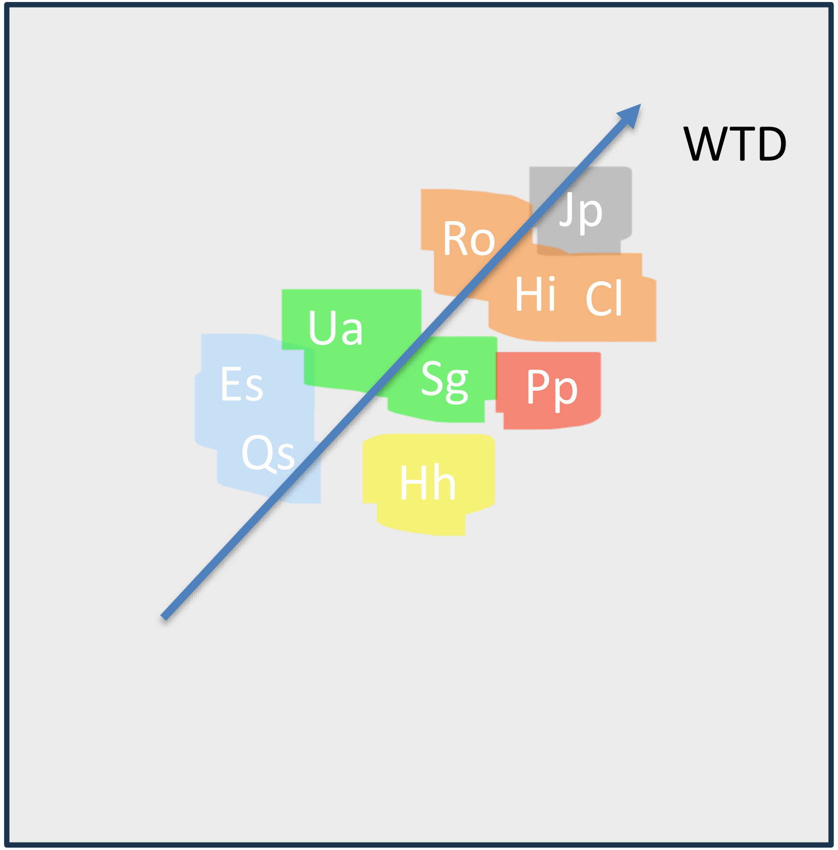
Species
Asparagus aphyllus
Calluna vulgaris
Chamaerops humilis
Cistus libanotis
Cistus psilosepalus
Cistus salviifolius
Corema album
Cytisus grandiflorus
Daphne gnidium
Erica scoparia
Erica umbellata
Genista triacanthos
Halimium calycinum
Halimium halimifolium
Helichrysum italicum
Juniperus phoenicea
Lavandula stoechas
Myrtus communis
Osyris lanceolata
Phillyrea angustifolia
Pinus pinea
Pistacia lentiscus
Quercus suber
Rosmarinus officinalis
Rubus ulmifolius
Smilax aspera
Stauracanthus genistoides
Thymus mastichina
Ulex australis
Ulex minor

3. Functional implications of water-table lowering

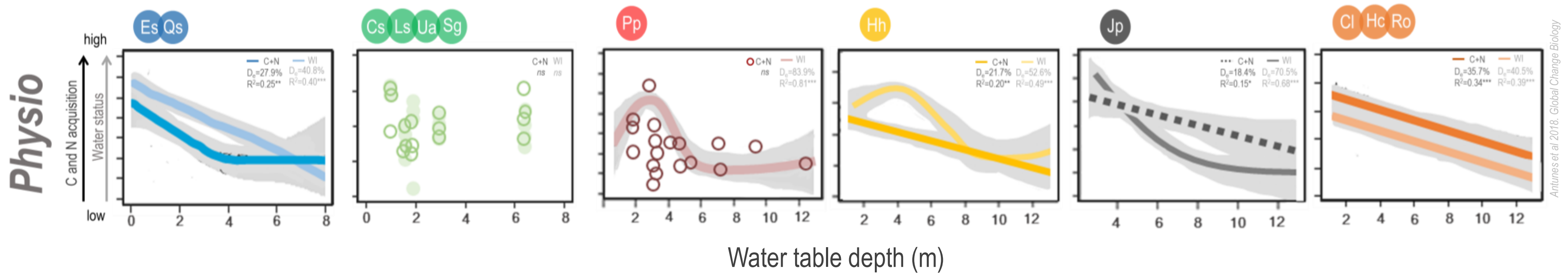


Antunes, C. et al (2024) *submitted*

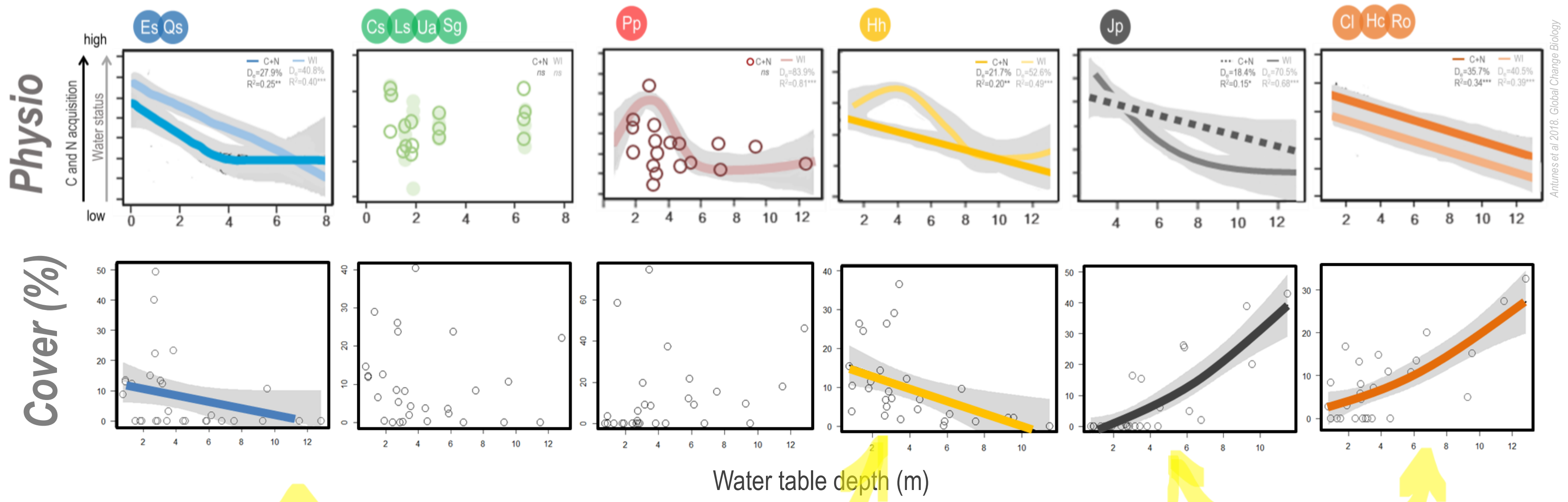
3. Functional implications of water-table lowering



3. Functional implications of water-table lowering



3. Functional implications of water-table lowering

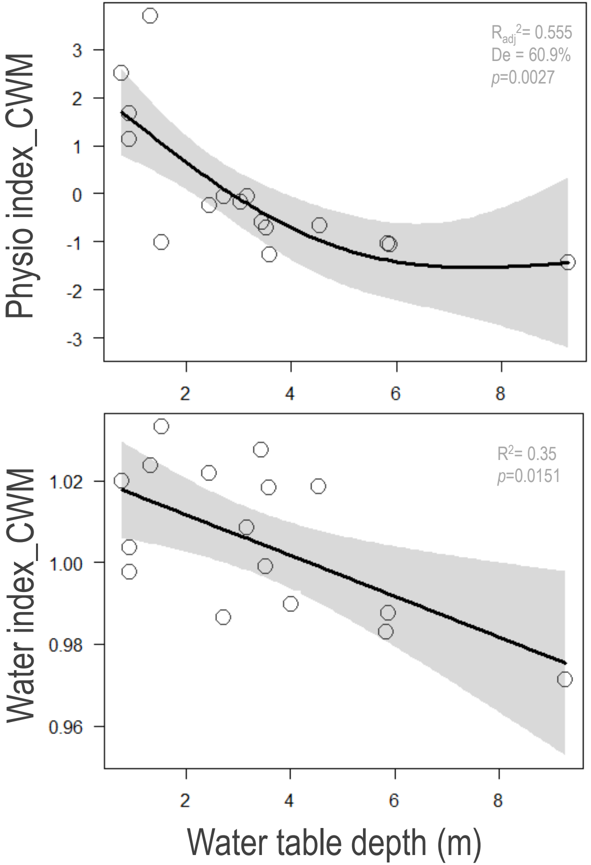


Physiological responses signaling further impacts of groundwater scarcity on species cover-groundwater-dependent species

Although physiologically affected by water-table depletion, xerophytic species (with different water-sources-use) such as J. phoenicea, R. officinalis and C. libanotis, showed an increasing cover with water-table lowering

3. Functional implications of water-table lowering

Community weighted mean



Dominant traits on shallow groundwater sites points to a community with a higher photosynthetic capacity and better water status

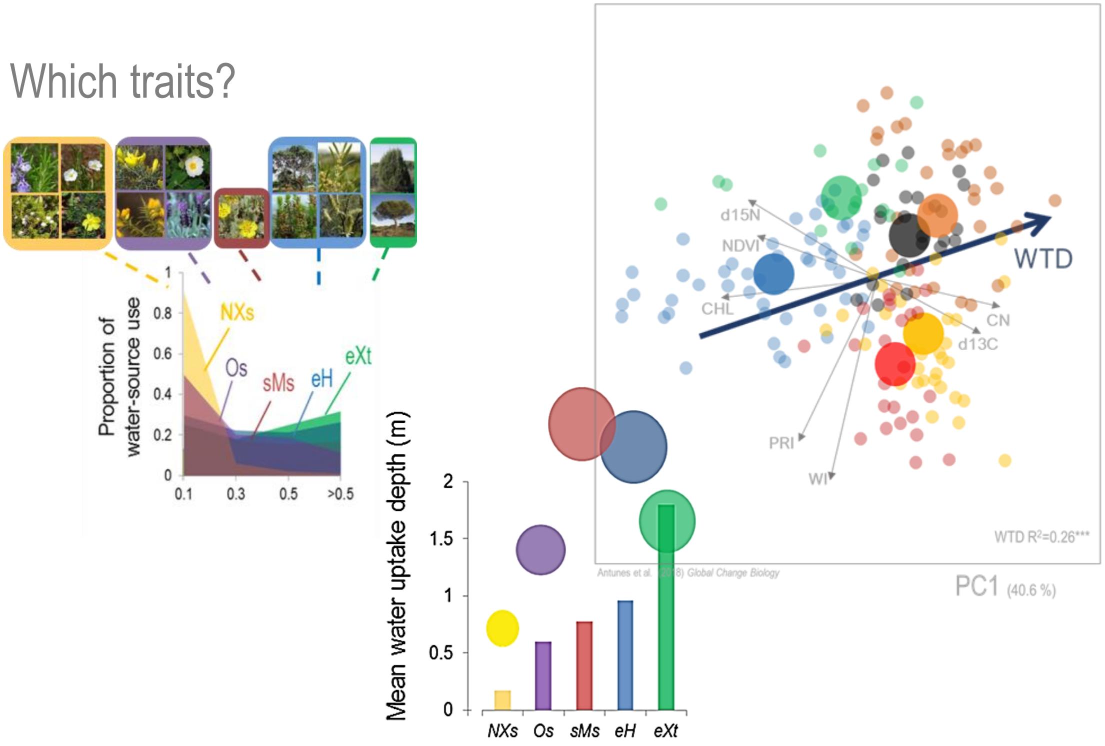
Valuable use of physiological indicators to trace shifts in the community due to groundwater depletion

Antunes, C. et al (2024) *submitted*

3. Functional implications of water-table lowering

Community functional diversity

Which traits?



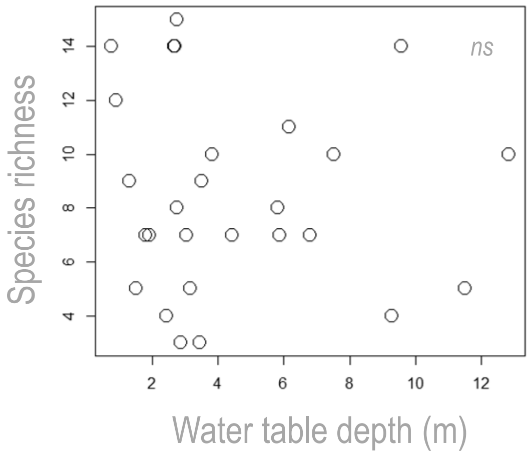
TRAITS

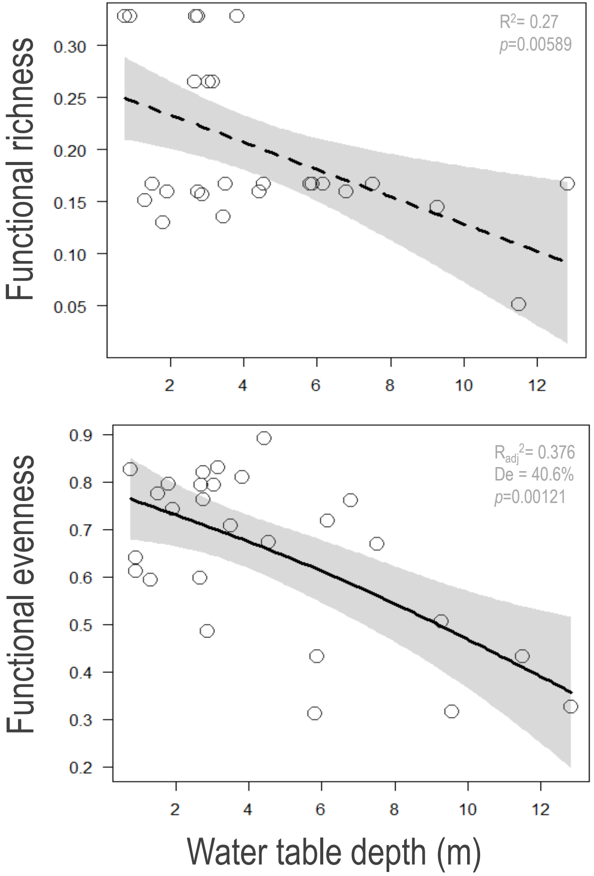
Leaf consistency
Leaf life span
Leaf margin
Trophic type
Leaf hair
Habitat preferences
$_{\text{average}}$Height

$_{\text{summer}}$water-sources-use
Water-use seasonal shifts
$_{\text{max}}$Water-uptake depth
$_{\text{average}}\delta^{13}C$
$_{\text{average}}\delta^{15}N$
$_{\text{average}}$C/N
$_{\text{average}}$Water index
$_{\text{average}}$NDVI

3. Functional implications of water-table lowering

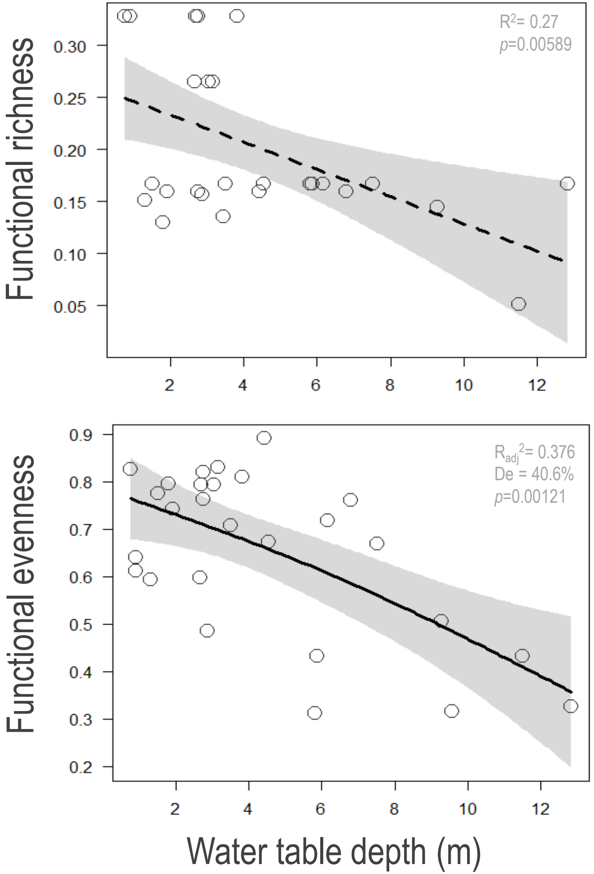
Community functional diversity





Antunes, C. et al (2024) *submitted*

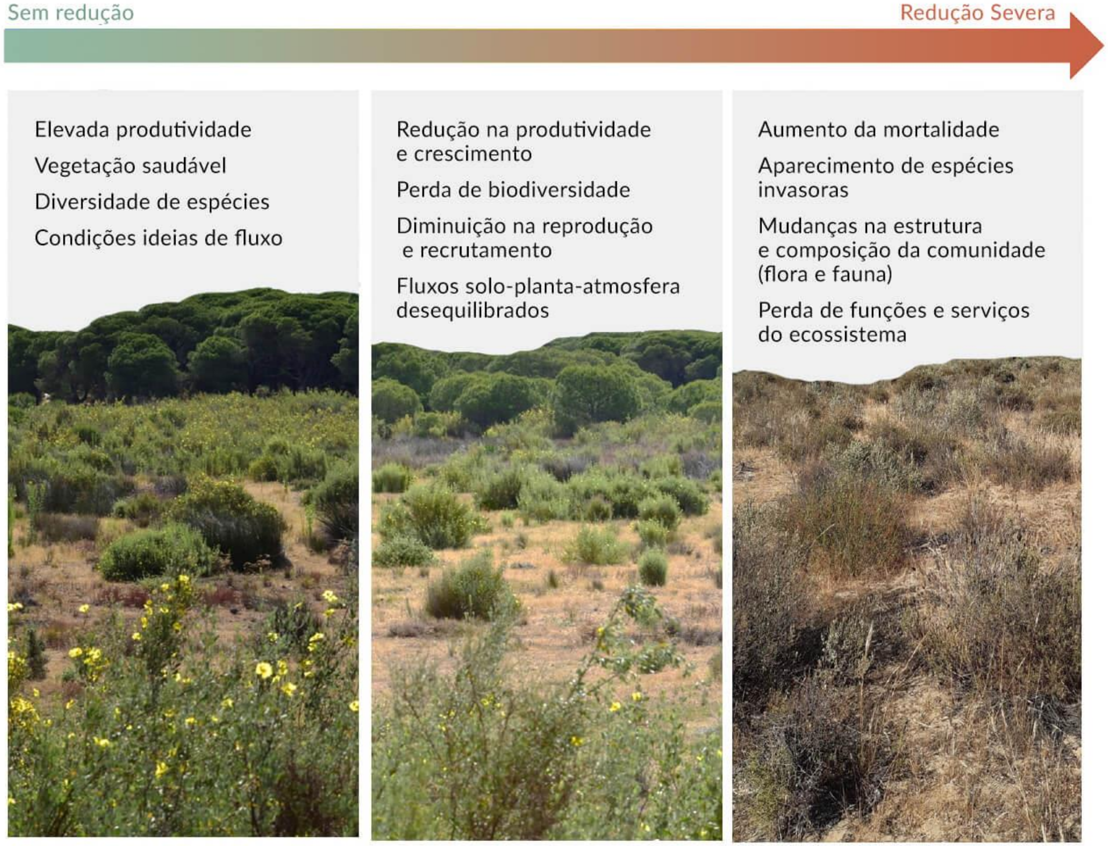
3. Functional implications of water-table lowering



Decrease in functional richness and evenness with groundwater lowering, reinforcing the functional impacts at ecosystem level

Take home messages

Consequências da redução da disponibilidade de água subterrânea em sistemas terrestres: declínio do estado ecológico de um ecossistema

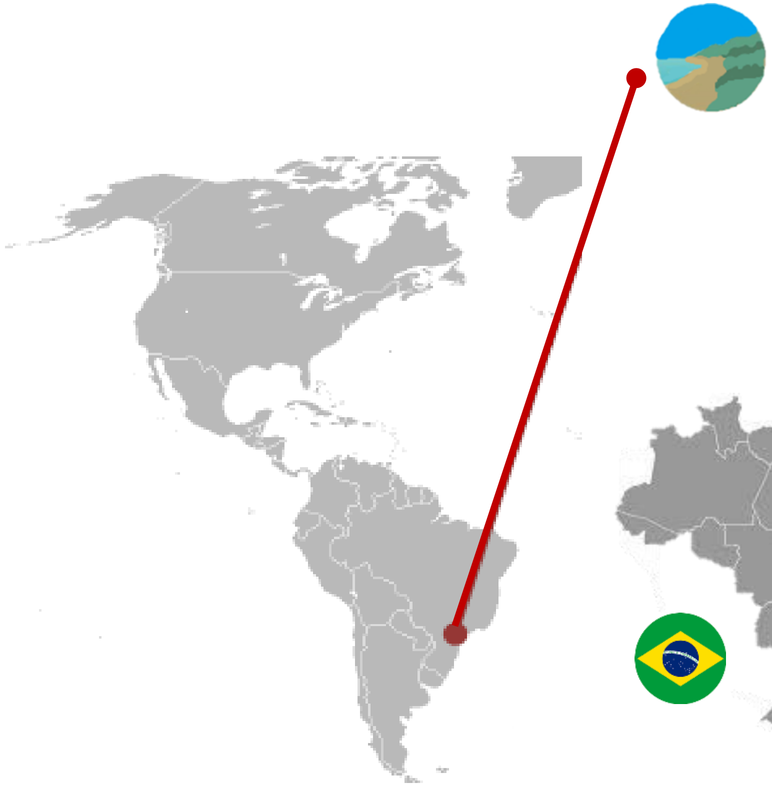


Take home messages

- Water-table lowering negatively affects the physiological performance of Doñana woody community
- Groundwater depletion influences ecosystem functioning
- Combining community structure with (multi-trait) physiological approaches is important to better trace the vulnerability of the vegetation to the decline in water sources

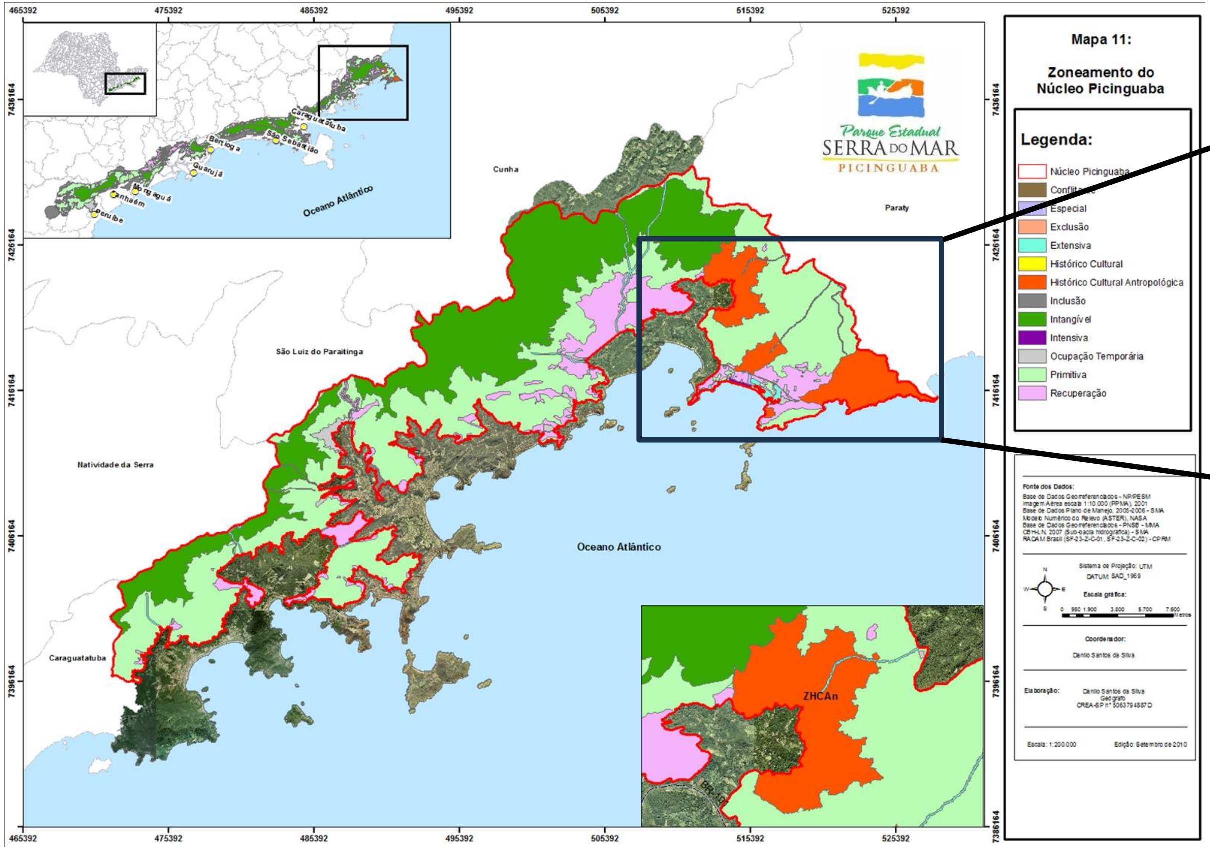
Where?

Where?

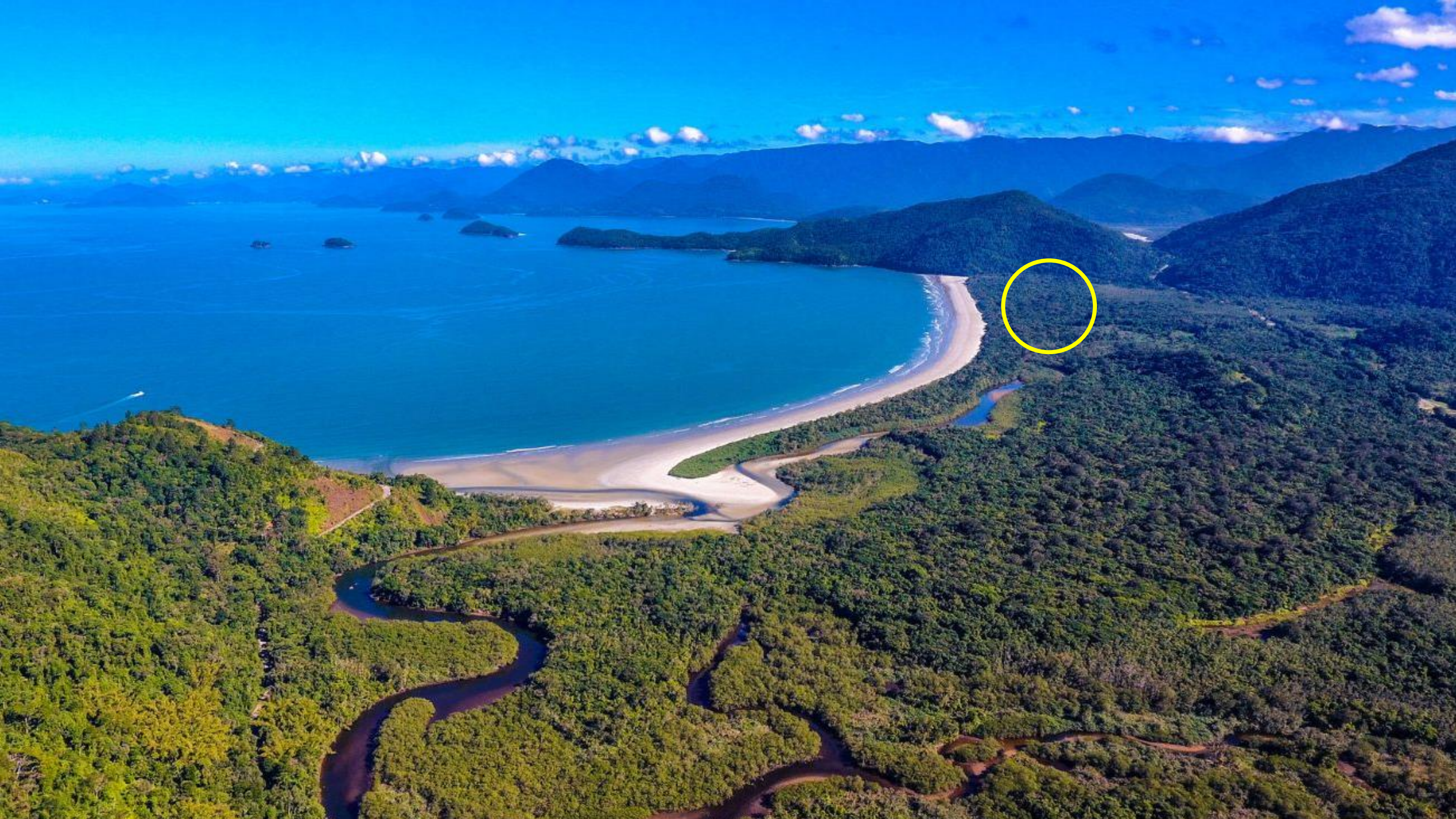


Parque Estadual
SERRA DO MAR
PICINGUABA

Where?



gradiente.funcional



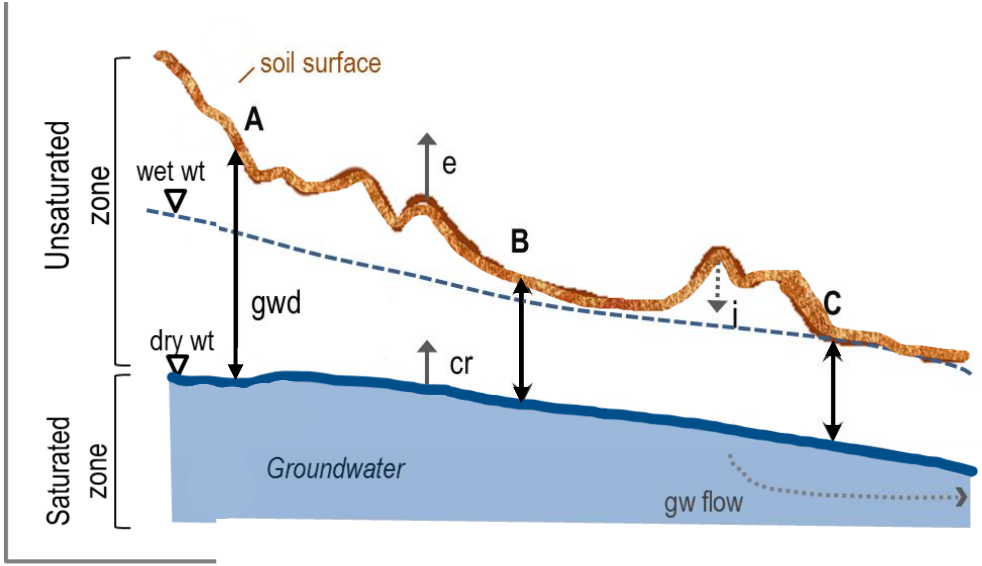
Where – *restinga* forest





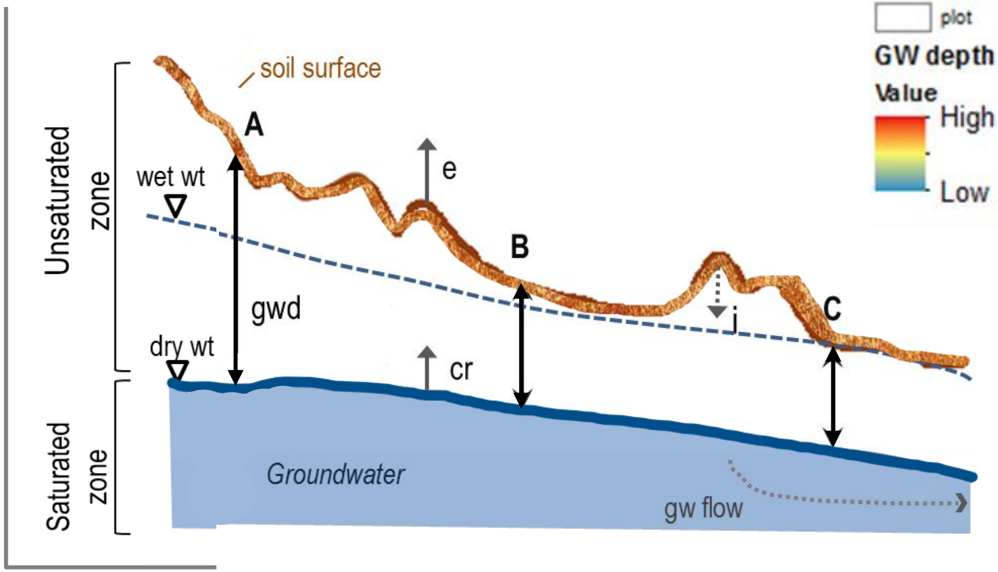
→ How water-table depth affects the vitality of a tropical dune forest?

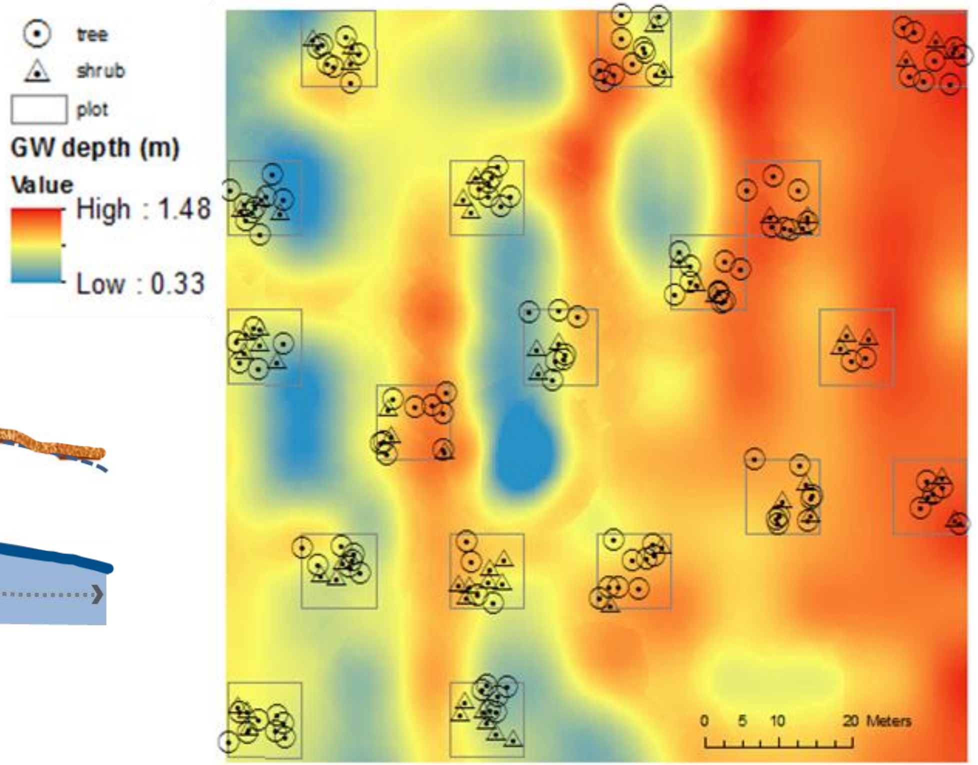
Spatial groundwater gradient



→ How water-table depth affects the vitality of a tropical dune forest?

Spatial groundwater gradient





18 sampling plots

→ How water-table depth affects the vitality of a tropical dune forest?

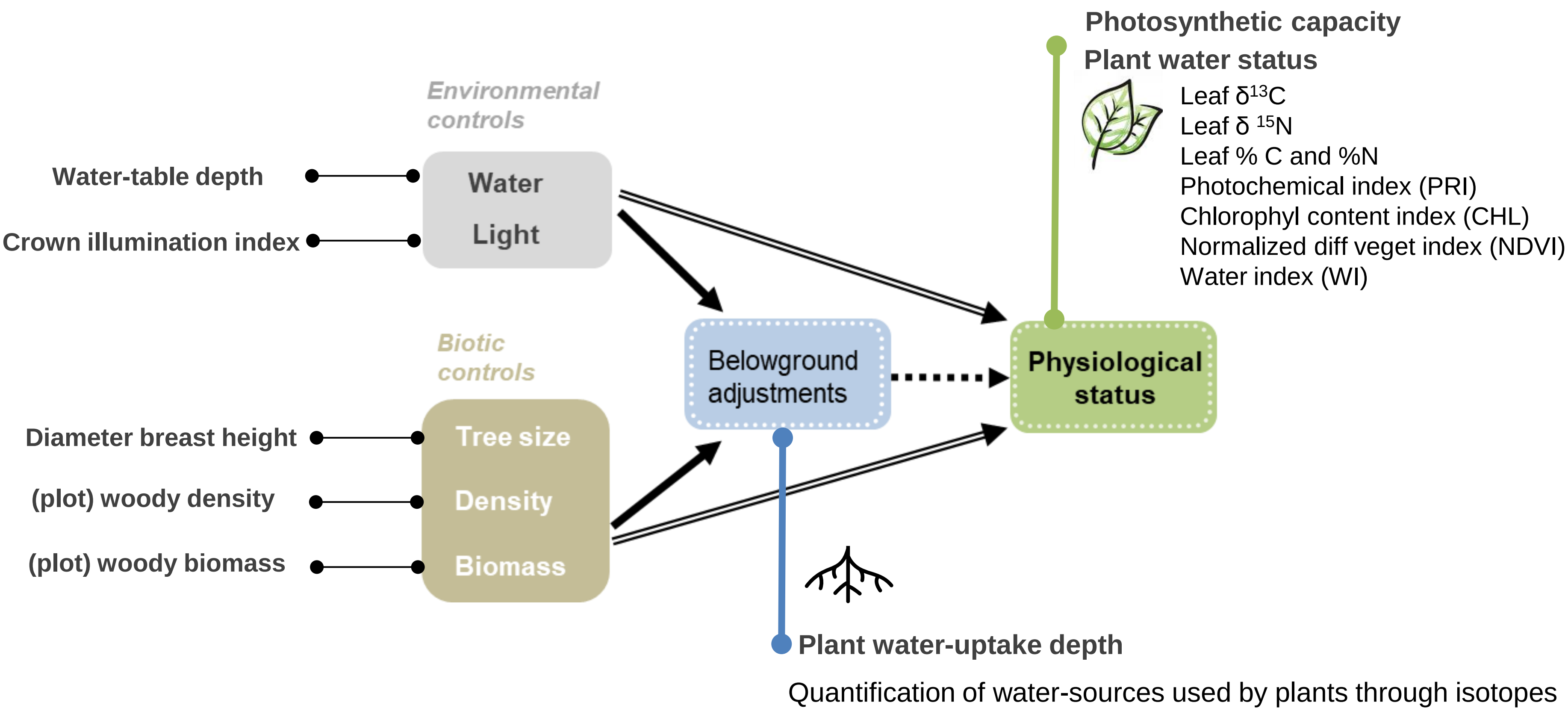
✓ Dominant coexisting 15 **woody** species

Species	n
Eugenia schuechiana	7
Euterpe edulis	4
Faramea pachyantha	4
Guapira opposita	7
Guarea macrophylla	4
Guatteria sp4	9
Jacaranda puberula	7
Marlierea tomentosa	4
Maytenus littoralis	9
Myrcia brasiliensis	4
Myrcia multiflora	13
Myrcia racemosa	5
Pera glabrata	5
Psychotria sp1	48
Psychotria sp2	9

Total 139 *per season*

Antunes C., et al (2019) *Plant and Soil*

→ How water-table depth affects the vitality of a tropical dune forest?

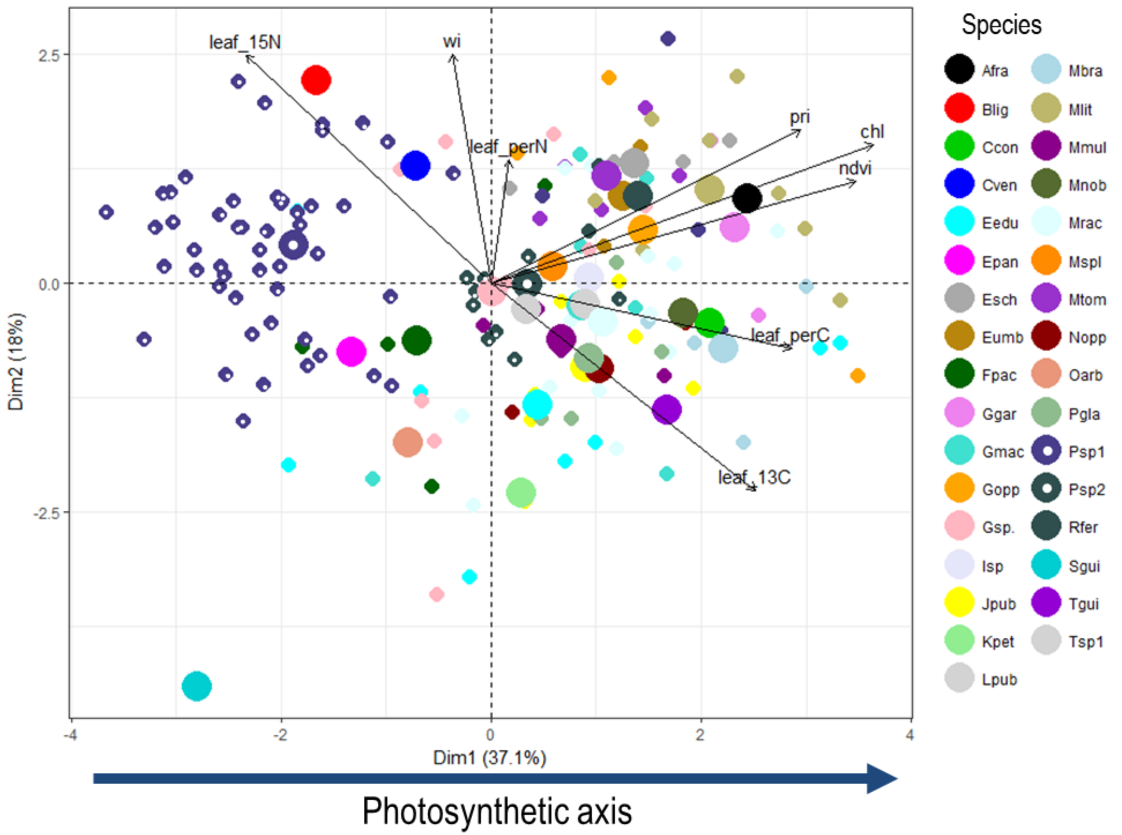


How water-table depth affects the vitality of a tropical dune forest?

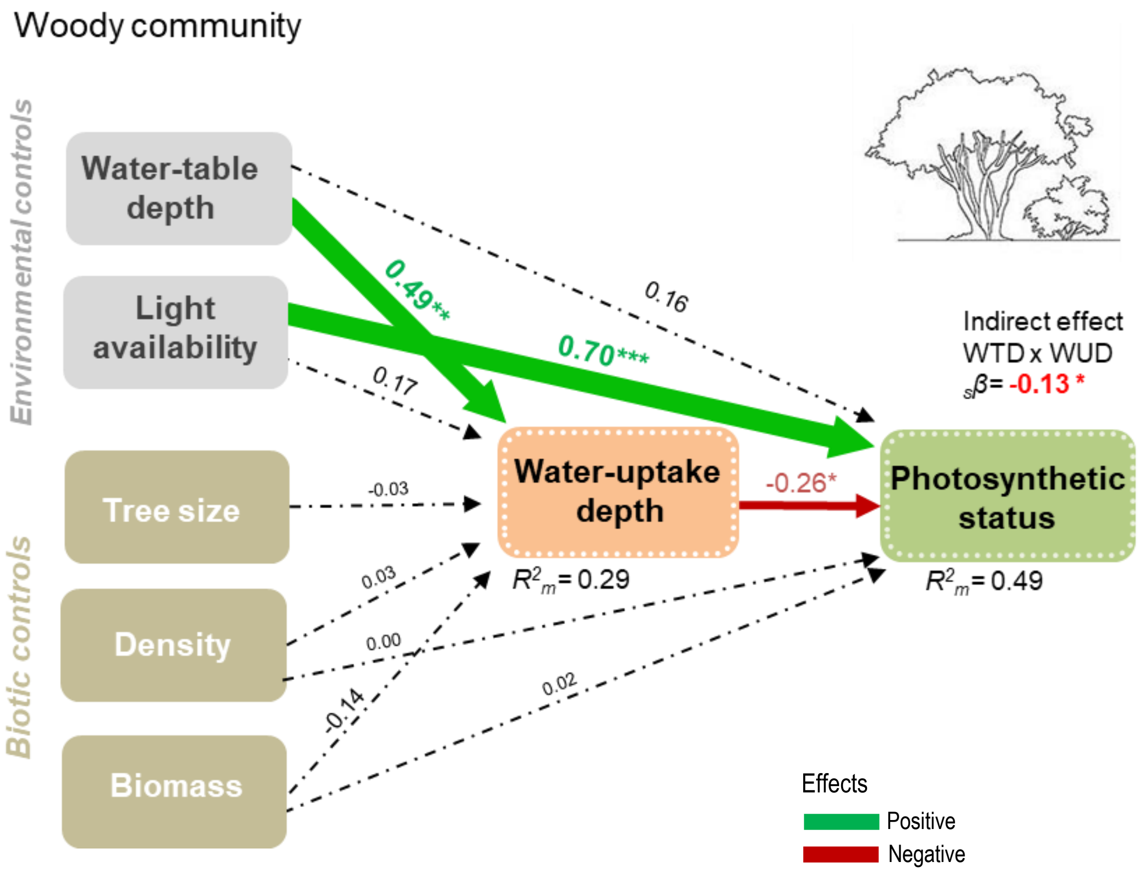
Physiological status

Photosynthetic capacity – PC1

Plant water status - WI



→ How water-table depth affects the vitality of a tropical dune forest?

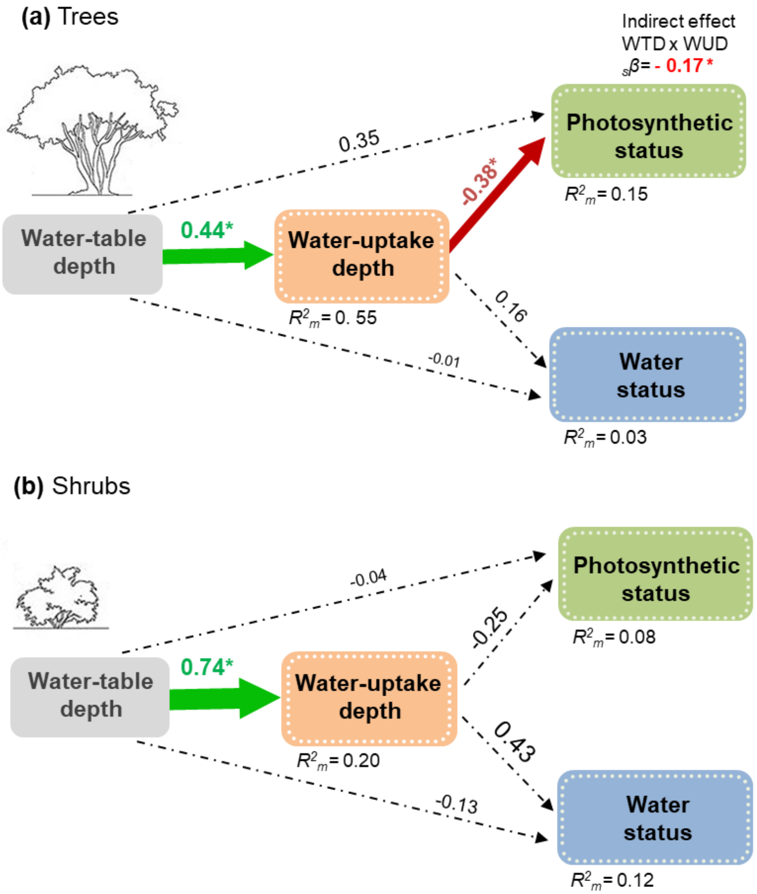


Light accessibility drives differentiation in woody vegetation physiological condition

Water-uptake depth is affected by water-table depth which in turn affects negatively plants' vitality

Indirect negative effect of water-table depth on photosynthetic capacity via belowground adjustments

→ How water-table depth affects the vitality of a tropical dune forest?



Water-table depth had an indirect effect on the physiological status of trees, influencing the photosynthetic activity through belowground adjustments.

Even at a fine-scale, greater depth to groundwater significantly influenced trees and shrubs water-uptake depth towards deeper soil layers, while promoting a decline in physiological status in trees.

Water-uptake depth adjustments have a significant negative influence on *restinga* tree species' photosynthetic performance, but not in understory shrubs.

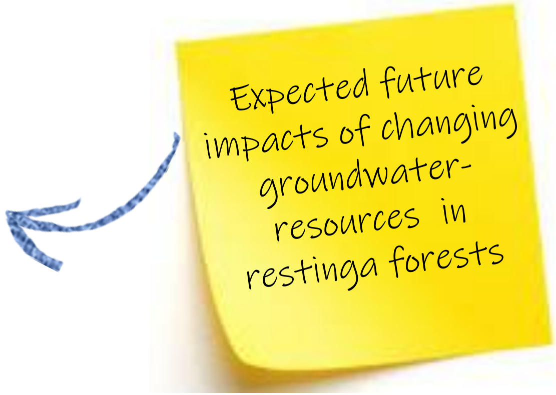
Take home messages

- The photosynthetic status of restinga woody community was mainly affected by the **direct positive effect of light access** → great differentiation between tree and shrub species
- There is an **indirect negative effect of lowering water-table mediated by belowground water-uptake adjustments** towards deeper soil layers
- **Trees** presented **lower physiological status when belowground investments were made** to reach deeper soil layers

Take home messages

- Our study highlights the influence of groundwater changes in *restinga* forests under rainless periods. **Water-table depth defines the water-sources used by both trees and understory shrubs**, reinforcing the **reliance on this water resource** and the **ubiquity of groundwater availability as a driver of root adjustments** and **belowground investments**.

- These adjustments have a **significant influence on the physiological performance of *restinga* trees**. Above and belowground investments may change with groundwater availability, and trade-offs of resources allocation are likely to occur



Obrigado!

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

fundação

UNICAMP

IB Instituto de Biologia

UNIVERSIDAD DE SEVILLA
DEPARTAMENTO DE BIOLOGÍA VEGETAL Y ECOLOGÍA

Parque Estadual SERRA DO MAR PICINGUABA

REN

cost

PELD PESQUISAS ECOLÓGICAS DE LONGA DURAÇÃO

PAUL SCHERRER INSTITUT PSI

MARIE CURIE ACTIONS

European Commission

CAPES

ce3c centre for ecology, evolution and environmental changes

Ciências ULisboa

TÉCNICO LISBOA

CERENA

Estación Biológica Doñana CSIC

SIIAF

NSF

FAPESP